PRELIMINARY CONSIDERATIONS OF VENUS EXPLORATION VIA MANNED FLYBY

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ABSTRACT

This report considers the Venus encounters associated with the 1977 Triple Planet Flyby and 1978 Dual Planet Flyby opportunities. A specific planetary reconnaissance program is described and a probe complement planned to accomplish the scientific and engineering objectives set forth.

Several of the probes are considered in detail. These are principally limited to floater devices which, in many ways, typify the type of systems necessary to accommodate the extraordinary constraints imposed by the Venusian surface environment.

A result of this study is a recommended probe complement with gross weights of 27,000 lbs and 17,000 lbs for the 1977 (dual Venus passage) and 1978 encounters respectively.

This study was compiled prior to the October, 1967 American Mariner flyby and Russian lander probe encounters. Based on the latest data available at publication, the concepts presented herein are consistent with the revised environmental models, however, due to the reduced uncertainties the conclusions are in some cases considered conservative.

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1.0 INTRODUCTION

This report considers the Venus encounters associated with the 1977 Triple Planet Flyby and 1978 Dual Planet Flyby opportunities.

The approach to Venus is different from the approach to Mars. The objective for Mars is to gain an extensive understanding of the planet and to provide sufficient information to answer the principal question, "should man land on Mars?" The Venusian objective is less ambitious because of our present lack of knowledge and the difficulty anticipated in gaining knowledge. Thus, one seeks to basically characterize Venus and gain sufficient data to provide for comprehensive exploration by more complex devices.

This report first describes a specific planetary reconnaissance program. Here the mission philosophy is developed, and a probe complement is planned to accomplish the scientific and engineering objectives set forth. The various aspects of Venusian atmospheric entry and the constraints imposed on time line sequencing and probe design are considered. In addition, the communications problem, as a limiting factor for site selection is reviewed.*

The probes are principally limited to floater devices which, in many ways, typify the type of systems necessary to accommodate the extraordinary constraints imposed by the Venusian surface environment.** The second part of this report covers the concepts and design approaches used to establish the feasibility of this class of Venusian probe.

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*This particular effort was supported by preliminary studies carried out by Messrs. C. L. Greer and J. J. Schoch. Since their efforts were extensively used they are referenced here (1 and 2) rather than repetitively through the text. Also of general interest is the entry study by D. E. Cassidy, Reference 3.

**Mr. M. Liwshitz contributed the discussion of experiments and instruments for the Buoyant Venus Device, a long life high altitude floater.

2.0 VENUS RECONNAISSANCE USING THE 1977 & 1978 FLYBY'S

2.1 Mission Profile

The three passes of Venus, provided by the 1977 and 1978 opportunities, will yield quite substantial coverage of the planet. Figure 1 shows the relative geometry for each planet,[1] pointing out the orientation of the planet with respect to the flyby trajectory and the major points and regions of interest, which are:

Sub-solar point

Anti-solar point

North pole

South pole

Terminator

Equator

Mid-light side

Mid-dark side

(the last two refer to the region approximately half way between the terminator and the sub-solar and anti-solar points, respectively.)

Specific surface points of interest are not yet clearly identifiable. However, radar studies have revealed surface features which may eventually assume a more important position in mission planning.[4] Therefore, the points of interest are essentially dominated by the relation of Venus to the sun. This is quite reasonable in that the small inclination of the Venusian equator to the orbit plane and the very slow rotation rate[5,6] (123 earth days = 1 Venus day) combine to indicate that the atmosphere is dominated by the sub-solar-anti-solar axis.[7,8] A further point of interest in that the poles are never inclined by more than a few degrees to the sun,[5,6] and may be the most likely locations for surface life forms. On the other hand, a temperate region exists at altitudes between 125,000 feet and 215,000 feet, which may also support life.[9,10]

2.2 Probe Complement

Several categories of probes are utilized for the various encounters. In later discussion the performance and design of the floater class probes are analyzed in considerable detail. However, as an introduction, the complete probe complement is briefly summarized:

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[1]Numbers refer to reference in Bibliography.

a. Drop Sonde/Atmospheric Probe (DSAP)

This probe is to obtain deceleration data at high speed and acquire direct atmospheric data at low speed. The low ballistic parameter (i.e., less than .3 slug/ft^2) and small size will permit reasonably steep entry. Large dispersions in time to descent through altitudes exist because of the present uncertainty in our knowledge of the Venusian atmosphere. Consequently, a high ballistic parameter (high density) drop sonde is also to be employed for low speed measurements. Following terminal condition, the sonde will be dropped through a port in the heat shield to make direct atmospheric measurements with the important advantage of having an ablation free "clean" surface.

b. Orbiter

The orbiter is propulsively braked into orbit and performs long duration R.F. and scientific mapping studies. The orbiter is also employed as data link for tracking and monitoring floater probes.

c. Meteorological Devices

Successful deployment and operation of advanced buoyant probes is to a great extent contingent upon having accurate knowledge of basic environmental phenomena which include:

a. The Venusian air stream circulation patterns,

b. The severity and extent of large scale atmospheric turbulence.

Meteorological probes (similar in concept to earth based constant altitude meteorological balloons) are deployed at varied locations and altitudes on the planet to study these phenomena. The meteorological devices are tracked by an orbiter deployed at an inclination and altitude to ensure radar coverage for a minimum of several weeks.

d. Photo - R.F. Probes

R. F. Probes are conceptually similar to the lunar Ranger vehicles, although aerodynamically decelerated in an entry cone. A low sensitivity aerodynamic configuration and a attitude stabilization system are used to minimize image distortion during descent. These probes will be capable of operations below the opaque Venusian cloud layer.

e. Lander Probes

Lander Probes obtain photographic, soil mechanics and surface weather data. Two classes of lander probes are conceived: large probes capable of photo coverage, and small probes. The small probes are associated with early missions and will be comparable to atmospheric probes in size and targeting capability. The small lander will be ejected from the heat shield similar to the drop sondes.

f. High Altitude Buoyant Venus Device (BVD)

The principal purpose of a buoyant Venus probe is biological exploration in the planet's atmosphere. Though the presumed rigorous conditions at the Venusian surface and near it may preclude the existence of life there, the atmosphere below the cloud cannot be ruled out as a possible abode of primitive "aerosol life." The advantage of the BVD in the search for life lies in its comparatively large payload capacity and in its expected long lifetime in environment not necessarily hostile to primitive life. The high altitude floater operates at altitudes within a presumed temperate belt which offers the greatest probability of fostering life as we know it. The BVD is maintained aloft by a large balloon with an inflator resupply sufficient to ensure a lifetime of at least one to six months.

g. Near Surface Floater

The Near Surface Floater (NSF) is designed to operate between 5,000 to 10,000 ft. above the Venusian surface and to descend to altitudes as low as several hundred feet if atmospheric conditions permit. The purpose of the probe is the exploration of the planet's lower atmosphere and, conditions permitting, aerial surface reconnaissance, aerosol and surface sample acquisition, and subsequent on-board analysis. Conceptually, the probe is a derivative of the deep submergence spheres used in the scientific exploration of the seas.

3.0 1977 TRIPLE PLANET - FIRST VENUS FLYBY

With the basic mission concept in mind the first passage of Venus is devoted to characterizing the atmosphere, and beginning surface exploration. The probe complement is planned as follows:

Six Drop Sondes/Atmospheric Probes (Total Wt. @ Entry, 1200 lbs)

Sub-solar Region (AP)* low g/common
Anti-solar Region (AP) low g/common
Terminator @ Equator (AP) steep ent.
Mid-light Side (AP)
Mid-dark Side (AP)

Four Meteorological Balloon Probes (Total Wt. @ Entry, 8300 lbs)

Sub-solar Region (AP)
Anti-solar Region (AP)
arbitrary (2)

Two Lander Probes (Total Wt. @ Entry, 1400 lbs)

North Pole Proximity (AP)
Mid-light Side (DE)

Two Photo-RF Probes (Total Wt. @ Entry, 1400 lbs)

Sub-solar Region (AP)
Mid-light Side (DE)

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*AP signifies that the probe completes the mission while the spacecraft is approaching periapsis, and DE signifies departure from periapsis.

One Orbiter (Total Wt. @ Entry, 8000 lbs)

Placed into a low, near polar orbit passing over sub- and anti-solar points at time of insertion.

Spacecraft On-Board Instruments

40" Telescope
Wide Angle Camera
Multi-spectral Photography
Spectrometer and Radiometer
U. V. Polarimeter
Topside Sounder
Mass Spectrometer
Side Looking Mapping Radar

The drop sondes/aerodynamic probes (DSAP) are delivered between ten and sixteen hours prior to periapsis. Although the communication range is large the bit rate is quite small, thus the power and antenna requirements are easily met. Early delivery of these probes essentially frees the crew to concentrate on the more demanding operations associated with the other probes. Furthermore, the DSAP probes will provide valuable information that may ease the operations of later probes. This arises from the dependence of sink time (time to descend to the surface from entry) on the surface density and lapse rate. For current atmosphere models[9] the sink times range from approximately ten minutes through sixty minutes for the high density sondes, (thus, about six hours for six probes). The actual times will be used to determine the sink times for the landers and photo-RF probes.

The meteorological balloon systems operate in conjunction with the orbiter and, thus, require no communications link with the spacecraft after entry. These devices will enter after -10 hours but prior to approximately -3 hours, thereby preventing interference with communications to the remaining probes.

The two small survivable type lander probes are deployed to locations that are in full view of the spacecraft. The probes require 10 minutes to 60 minutes sink time and transmit for one hour after impact. The first lander enters at -3.0 hours and the second at +1.5 hours. Thus, regardless of the actual sink time, the first lander sequence is finished by -1 hour, and does not commence again until +1.5 hours without any communications overlap being required.

At -1 hour the first Photo-RF probe (sub-solar region) will commence transmission which will last from 10 minutes to 60 minutes. At +0.25 hours the second probe (mid-light side) begins transmission. It is necessary to confine Photo-RF probe operations to approximately $\pm$ 1 hour of periapsis because of the relatively high bit rate associated with the photographic mission, $\sim 10^6$ bits per second. This also results in the need for a steerable antenna on the probe.

The orbiter will be preprogrammed for insertion at approximately periapsis time, to minimize the propulsive penalty.

The drop sonde probes will obtain density, pressure temperature, upper atmosphere composition and limited wind profile data. Since the lower atmosphere is expected to be symmetric about the solar axis (with only mile deviations introduced by the poles and rotation) this set of target regions should reveal the basic pattern of the atmosphere. The impact data from the survivable landers may aid in characterizing the surface at particular points when used in conjunction with the orbiter, lander and Photo-RF probe data.

However, the drop sonde probes cannot significantly aid in establishing the dynamics of circulation patterns of the atmosphere. To accomplish this the meteorological balloon probes are employed to float from three to six different altitudes for long periods. These systems are deployed in the orbiter plane along the great circle between the sub-solar and anti solar points. Tracking, via the orbiter, over a period of weeks is expected to reveal the long term circulation patterns.

The survivable lander probes will provide soil mechanics and weather data for about one hour at two surface locations. The north pole proximity is reached via a very steep entry on this passage of Venus. The mid-light side region is selected for the second probe to measure the upper bound of surface illumination. The information from these probes will be used to calibrate the X-band mapping radar on the orbiter and the S-band mapping radar on the spacecraft, to aid in interpreting the significant of varying surface dielectric constants.

Photo-RF probes provide a wide angle picture every ten seconds during descent, until impact. The probe is stabilized to maintain the optical axis on the gravity axis and to maintain the communications link. These probes will also obtain pressure, temperature, density, limited wind and impact data. The sub-solar point is selected because of the relatively unique conditions expected, although these may include considerable cloud cover and dust. Probably the lander and Photo-RF probes will be sent to essentially the same location on the mid-light side region to yield a microscopic view and a close surface view of this location (the drop sonde would be deployed to an entirely different mid-light side target). Lights and flares will be utilized to improve lighting conditions below the clouds. Again, the Photo-RF probe data will be used to provide calibration information for the orbiter and spacecraft mapping radars.

The orbiter will scan the entire planet in about 120 days because of the near polar orbit. The orbiter provides multi-spectral scanning, X-band surface mapping, meteorological balloon tracking and data on the gravitational shape of the planet. A low orbit is selected to improve the quality of the scanning and mapping data. The first stage of the orbiter insertion propulsion system will fall into an elliptic orbit and is, thus, useful for determining the gravity perturbations.

In summary, at the close of the first Venus encounter of the 1977 mission, the atmosphere will be quite well characterized with regard to altitude distribution of properties and circulation patterns. The surface will have been entirely mapped via the X-band orbiter radar at low resolution, and limited regions will be mapped by the spacecraft high resolution S-band radar. The mapping data will be interpreted via the lander and Photo-RF probe data. Direct surface data will be obtained from the landers and impact data from the drop sondes and Photo-RF probes.

The probe complement for the second encounter is selected to take advantage of this substantially improved state of knowledge. By August, 1978, 14 months after the first pass, numerous surface locations of interest should be known from the mapping data. Further use of the drop sondes and meteorological balloons would be somewhat pointless as the atmosphere should be sufficiently well characterized to permit the generation of specific questions, which should be attacked with new probes designed for such purposes.

Consequently, the emphasis for the second pass probes is placed on surface exploration. Unfortunately, one cannot at this time, predict the specific surface locations of interest that will result from the first pass data. Obviously, if such were possible the deployment policy would be different. Future investigations via earth bound radar scans from Arecibo and Goldstone may well shed light on the major surface features, thus, changing the probe policy discussed herein. Regardless, it remains pertinent to discuss the possibilities for the second passage, since it is still quite likely that the emphasis will remain on surface features.

4.0 1977 TRIPLE PLANET - SECOND VENUS FLYBY

Five Lander Probes (Total Wt. @ Entry, 3500 lbs)

To be deployed on the basis of the knowledge gained from the first passage. Possibly most desirable on light side because of increased visibility.

Five Photo-RF Probes (Total Wt. @ Entry, 3400 lbs)

To be deployed on the basis of the knowledge gained from the first passage. Not restricted to light side.

Spacecraft On-Board Instruments

40" Telescope
Wide Angle Camera
Multi-spectral Photography
Spectrometer and Radiometer
U.V. Polarimeter
Topside Sounder
Mass Spectrometer
Side Looking Mapping Radar

As in the first passage the deployment of the lander probes is staggered so that the landers arrive either before or after the Photo-RF probes, thus, enabling the communication range for the latter to be minimized. On this passage there will be no question of sink time dispersion since data will be available from the previous encounter. It is quite unlikely that all probes would be delivered at points to which communications can be maintained during both Venus approach and departure. Therefore, the same communications ranges are used; i.e., $\sim$ 1 hour for the Photo-RF and $\sim$ 3.5 hours for the lander.

At the conclusion of this passage seven locations on the planet will have been investigated for soil mechanics, weather and photographed. Eight locations will have been surveyed via nested photography and impact measurements. And the orbiters and spacecraft radar mapping will be quite thoroughly calibrated for interpretation. The total weight of Venus probes carried on the 1977 mission is 27,200 lbs.

With the atmosphere characterized the surface mapped and the environment measured, it is appropriate to move onto the search for life and extended surface operations. The 1978 Dual-Planet Venus payload is directed at these problems by use of the high altitude and low altitude long life floating probes. The high altitude floater is designed to operate in the temperate regions (0°F to 100°F) where it is reasoned, earth like life forms have the greatest likelyhood of existing. The low altitude floater can be adjusted to float from the surface up to 10,000 ft to accommodate variations in ground plane altitude. This also permits use of the device even if the surface turbulence environment is prohibitive.

5.0 1978 DUAL PLANET - VENUS FLYBY

Two High Altitude Floating Probes (Total Wt. @ Entry, 6200 lbs)

To be deployed on basis of 1977 mission data.

Two Low Altitude Floating Probes (Total Wt. @ Entry, 6800 lbs)

To be deployed on basis of 1977 mission data.

One Orbiter (Total Wt. @ Entry, 4000 lbs)

Fulfills the communications link between earth and the floaters.

Both probes are equipped for high data rate transmission to the spacecraft for about six hours range from the planet. Thereafter, the probes will communicate to earth via the orbiter. During the first six hours the high altitude device will sample (by filtration) very large quantities of the atmosphere for life detection. The low altitude probe will be transmitting photographic scans of the area it is floating over. Should this be considered a desirable location for extended experimentation the probe will be anchored. If not control will be passed to earth.

The extended capability of this probe includes surface sampling and subsequent chemical analysis, emplacing a seismometer, a weather station and multi-spectral photography. The high altitude floater essentially continues, at a reduced communication rate, the experiments initiated on deployment. As mentioned the particular sites to which these probes will be delivered is not known at this time. However, one can reasonably speculate on desirable locations. The orbiter is a constraining factor in that it must be placed into an orbit that will permit near continuous communications with the floaters. This in turn constrains the target points for the floaters.

The low altitude device is constrained to regions of relatively low winds and smooth terrain if it is to operate very near the surface ($\sim$ 100's of feet). Otherwise, it must be used at quite high altitudes ($\sim$ 1,000's of feet) to avoid terrain or avoid destruction by turbulence. Earlier the poles were mentioned as regions where the probability of finding life on Venus is highest. Fortunately, regions near the south pole and the north pole are within the low deceleration entry regions for the 1978 passage. Consequently, it is quite likely that one of the low altitude devices will be deployed to one of the poles. The second may go to the opposite pole or any other likely region within the low entry zone. The passage geometry of the 1978 mission yields good coverage of the planet as seen from Figure 1c. Another interesting mission for the low altitude floater would be to anchor it at any arbitrary location on the equator and, given a lifetime of some 250 days, it will yield data on an equatorial diurnal cycle.

The high altitude floater will be completely controlled by the circulation pattern (Fig. 2), which is believed to be directed along great circles moving from the sub-solar point to the anti-solar point. Of course, a counterflow occurs at lower altitudes. Should this concept be confirmed, then both high altitude floaters will eventually be trapped at the anti-solar point. Analagously the anti-solar point may also be a stable trap for any airborne form of life.

Thus, one may obtain a high altitude survey of Venus by placing the high altitude floater near the sub-solar point and permitting it to drift to the anti-solar point.

The total entry weight of Venus probes carried on the 1978 mission is 19,000 lb.

By the close of the 1978 mission, Venus will have been quite thoroughly explored in terms of placing us in a position of knowing the basic physical information about the planet. The atmosphere will be extablished, though not necessarily understood. Numerous points on the surface will have been investigated, two for extensive time periods. Finally, the possibility of life forms will have been investigated within the scope of our current knowledge.

6.0 FLOATER PROBE CONCEPTS AND DESIGNS

Based on present knowledge of the Venusian atmosphere, extensive long range exploration can be most suitably performed by floaters of the type considered here. If manned exploration of Venus is eventually to be attempted the exploration mode could well employ a class of propeller driven cruising vehicles. Such a vehicle, employing nuclear power could provide the extensive mobility that a lander could not; all the more important, since the hostile Venusian environment will most probably necessitate man's confinement to his immediate shelter area or the shelter itself. The near surface floater represents a first step in achieving this design.

The following sections discuss the precursory floater class probes designed to explore and chart the Venusian surface and atmosphere.

7.0 METEOROLOGICAL DEVICES

7.1 Probe Rational

The spatial distribution and temporal variation of the Venusian atmosphere circulation patterns are themselves of fundamental scientific interest. Moreover, the explanation of related phenomena such as the high darkside temperature [very likely a result of convective transfer from the high energy (sub-solar) regions to the low energy (anti-solar) regions][11] is intimately coupled to understanding both long term (mean) and short term (cellular) atmospheric movements.

In addition, successful deployment and operation of advanced buoyant probes, to be delivered during the second 1977 and 1978 Venus encounters, is to a great extent contingent upon having accurate knowledge of basic environmental phenomena which include:

1. The Venusian air stream circulation patterns,
2. The severity and extent of large scale atmospheric turbulence,
3. The nature of localized storm effects, and the severity and extent of electrical discharges.

Meteorological probes (similar in concept to earth based constant altitude meteorological balloons), are deployed at varied locations and altitudes on the planet to accomplish the scientific and engineering objectives required for understanding these phenomena. These devices are tracked by an unmanned orbiter which is deployed at an inclination and altitude to ensure radar coverage for a minimum of several weeks. Time sharing with orbiter experiments will probably limit tracking time to four orbits a day. (Mr. E. J. Klein provided the preliminary designs of the communication and tracking systems used for the various meteorological devices.)

7.2 Mission Profile

Probe deployment to a minimum of four locations is required to achieve acceptable spatial coverage; however, six locations are strongly preferred. The targeting areas lie approximately in a plane which includes the sun line axis, and which is compatible with the observation constraints of the orbiter. These preferred locations are the sub-solar and anti-solar "singularity" points, a pole, and typical terminator, lightside, and darkside points as shown in Figure 2. The points are all accessible by shallow angle entry on the first or second Venus encounter 1977 triple planet flyby, with the exception of the poles which lie beyone the planet horizon. (The poles are, however, accessible during the 1978 dual planet Venus encounter.)

To achieve adequate vertical coverage, three to six meteorological devices designed to float at varied altitudes are delivered to each selected site in a single entry shell and ejected in a sounding sequence during descent through the terminal velocity regime.

Each floater probe is packaged in a separate cannister with individual chute, inflator, and pressurization systems. The floaters are deployed individually by parachute on command from a timer. Deployment to inflation is approximately 75-90 seconds.

Because of the high atmospheric temperatures and long term operational requirements, meteorological devices floating in the lower atmosphere are passive, or actively cooled. In the passive design concept the probe size is governed by the requirement to obtain a sufficient radar cross section for tracking within the constraints imposed by orbiter power limitations. The altitudes at which these devices actually float may be determined in retrospect from density and altitude data obtained from separate aerodynamic probes, also delivered during flyby encounter. With this scheme, an active on-board altimeter is not essential to the success of floater probe operation, which greatly simplifies probe design. Varied radar cross sections distinguish the possive air streams at different altitudes.

Active communications and experiments are included on-board the high altitude floaters operating in the temperate regimes, allowing local turbulence spectrum measurements, electrostatic discharge intensity measurements, and local state conditions to be obtained.

7.3 Probe Description

All of the floaters are hydrogen inflated "super pressure" class balloons[12] operating with a slight overpressure of about 1 to 10 millibars. A super pressure balloon is sealed from the atmosphere and maintains a constant buoyancy regardless of the thermal cycle experienced by the balloon during operation. This type of system will then permit long period operations. Some small balloons have, in fact, been in operation (floating) for over six months in the earth's atmosphere.

There are three classes of meteorological floaters considered here which are designed for operation in essentially three different thermal regimes. Based on the temperature distribution of the "mean" model atmosphere, floaters operating between the surface and 65,000 ft will be subject to operating temperatures above 500°F. Right at the surface, temperatures presumably as high as 1,000°F may be experienced. In this temperature range, state-of-the-art polymer fibers are inadequate. A material of super-alloy steel fiber weave (impregnated with silicon polymer filler) has been developed and is operational to temperatures between 1,000 - 1,200°F.[13,14] This material has, in fact, often been successfully employed in the fabrication of high speed entry balloons and parachutes. Below 1,000°F the impregnated steel weave material has a very low permeability to hydrogen so long life operation can be assured.

Between 65,000 ft. and 130,000 ft. temperatures range from 200 to 500°F for which Kapton film[15,16] (essentially a Mylar type polymide) is acceptable. For the temperate region above 130,000 ft standard Mylar polymide is used. Permeability of polymer film laminates to hydrogen gas is tolerably low (and reasonably predictable) and, hence, should not pose a problem during the first several weeks of operation.

7.3.1 Low Altitude Meteorological Devices

Three probe concepts are candidate for low altitude systems. There are:

a. Passive/Reflectors,

b. Active/High temperature sensors, and

c. Active/Actively cooled sensors.

Each system results in a markedly different weight allocation and hence, is analyzed separately.

a) Passive/Reflection

Employing a strictly passive system, floater size and configuration are dictated by orbiter tracking requirements. In the current mission mode the orbiter is to perform scientific observations and mapping experiments as well as probe tracking, and thus, cannot be solely devoted to the support of meteorological probe operations. Furthermore, the growth factor (ratio of gross weight to payload) for orbiter injection into a desired 400-500 km low circular orbit is approximately 10, so that antenna and power weight for probe tracking are quite limited. Keeping these factors in perspective, the following constraints are imposed on the orbiter tracking system:

1. Maximum antenna diameter is 3 ft. (weight dictates a parabolic reflector).

2. Prime power available is 250 watts (as compared to 125 watts for experiments and communications). Assuming that rechargeable batteries are employed, tracking is limited to every third or fourth orbit to minimize increased solar cell weight.

3. The tracking system weight limit is 65 pounds, not including conversion, acquisition sweep programming, and switching equipment. Raw data is to be transmitted to earth and appropriately reduced to improve tracking performance.

4. X-band operation compatibility is required.

The baseline system employs a rotating dish capable of a 50° angular sweep off the orbital plane. (In lieu of a rotating dish, a fixed antenna system employing a sector scan is suitable, but is not considered here.) From the above ground rules, the approximate system performance compatible with reasonable probe reflector sizes is:

1. Range resolution 5 km

2. Angular accuracy $\pm$ 0.75°

3. Angular discrimination 3°

The probe reflector shape considered is a 60° (apex angle) triangular trihedral of a minimum 1.5 meter dimension. The gain of the reflector is approximately 50 db which is adequate for tracking purposes. To distinguish the probes, the size of the reflectors are varied. Doubling the dimension increases the gain by 12 db, which should be quite adequate for this purpose. The reflector response gain is flat over ± 45° so that reduction of gain is not effected by the look angle or vertical misalignment due to wind gusts, which could otherwise make probe identification uncertain. Reflectors of this type can be deployed inside RF transparent balloons, as is commonly done for tracking meteorological floaters. The metallic weave required for the low altitude floaters is opaque to RF and, therefore, the reflector is externally supported by a toroidal balloon as shown in Figure 3. The required toroid cross section diameter varies from 1-3 ft. for the different altitude densities. (A standard 5-8 mil metallic fabric with 0.5 mil weave weighs approximately .21 lb/ft^2 and the material has a strength of 200 lbs/ft.) For packaging requirements, the super-alloy weave is readily folded and has the handling qualities of cloth fabric.

The reflector is fabricated of beryllium mesh to minimize weight and drag. Ballast is used to stabilize the probe in winds. The system weight of the balloon systems (including the reflectors) is approximately 250 lbs.

Each probe is packaged in a separate cannister and deployed from the parent entry module by parachute. Each floater requires a separate inflation system for which a substantial penalty is paid in inflator storage weight. (It requires 11 lbs. of bottle weight to store 1 lb. of H_2 inflator.) Consequently, the storage bottles are discarded immediately upon inflation. It may be noted that the small amounts of H_2 required for the individual probes does not make a common storage system economical.

b) <u>Active/High Temperature Sensors</u>

The large size of the passive low surface floater required for skin tracking makes them extremely heavy. The skin, inflator, and consequently, inflator storage weight, are far in excess of what is required for an active system capable of performing at high temperatures. In fact, meteorological probe weight reductions of over 50% could result if an active system without active cooling were employed. On the other hand, actively cooled systems, as later considered, are somewhat heavier than the passive probes (discounting orbiter penalties).

Relatively little work has been done in the area of active high temperature systems of the type suited for operation in the Venusian atmosphere. Quite simply, this is because the limited need for such instrumentation has not provided sufficient impetus for its development. Some intriguing concepts which are currently in the early research stages show considerable promise for high temperature performance. Several of these systems[17,18] are cited below:

1. RF Thermionic Converter -- It has recently established that significant amounts of RF energy may be generated directly from heat in a thermionic diode. The appearance of RF oscillations in the frequency range from 100 kc - 2 mc have been observed, which has led to their possible use for communication purposes. The waveform of the RF oscillation often departs from a sine wave, and the "frequency" depends on loading. This, however, should still be acceptable for a beacon or, possibly, a low bit rate communicator.

   During operations the Converter cathode is internally heated by radioactive decay to a temperature of 2,000°-3,000°K to excite electron emissions. The electron current is collected by the anode which is at 500°-1,000°K, coincidently the "reservoir" temperature of the Venusian atmosphere.

2. Electronic Tubes and Circuit Components are being developed, which presumably are useful at frequencies up to S-band and to temperatures of 900°F.

3. Devices useful in amplifiers and logic circuits have been built from ferro-electric ceramics. Current maximum operating temperature of $\sim$ 500°F probably could be raised to 600°F with further development.

4. Quartz crystals for frequency control with accuracy from one part in 10^6 to 10^7 are available at 850°F if adequate temperature control is provided.

c) Active/Actively Cooled Systems

An actively cooled instrumentation package has the clear advantage of: 1) providing a cooperative target for the orbiter tracker and, 2) supporting an experiments payload. These factors result in orbiter design simplicity, enhanced tracking (i.e., ranging) accuracy, ease of probe discernment, and a time history of atmospheric turbulence and state conditions. The disadvantages of the actively cooled system are limited probe duration (from several weeks to a month), increased probe complexity and weight, and altitude variation (due to weight changes resulting from coolant boil-off).

Experiments (Low Altitude Devices)

Experiments for the meteorological probes are for simplicity limited to basic environmental sensors. The experiments complement is given below:

	Weight (lbs)	Power (watts)
Pressure	0.5	1
Temperature Sensors	0.5	.2
Spherics Detector	3.5	2
Accelerometers	1	1
TOTAL	5.5	∿ 4

Pressure and temperatures sensors, besides providing state variable measurements, enable the floater altitude to be determined by correlation with aerodrag probe data.

The spherics detector senses electrical storms, and the accelerometers measure wind gust intensity and provide data for determining the atmospheric turbulence spectra. (These experiments are important for the use of advanced floater systems.)

Communications and Power (Low Altitude Devices)

The probe transmits the envelope of peak spherics and accelerometer data on command from the orbiter during a portion of each orbital tracking period, (i.e., every fourth or fifth orbit). A bit rate of 100 bps is adequate for tracking and telemetry via an omni-directional antenna. Transponder and communications weight, compatible with the orbiter specifications cited previously, is approximately 15 lbs.

Approximately 20 w total prime power (for communications and experiments) is provided by a thermionic converter. The power system is mounted on the exterior of the shell to minimize internal heating. The thermionic connector is readily capable of operating at a sink temperature well above the highest environmental temperature.

Coolant System (Low Altitude Devices)

The payload is protected by an evacuated double walled shell fabricated of semi-monoquoque beryllium skin. Reflective foil insulation is also employed to minimize radiation losses. A water jacket, interior to the shell, surrounds the payload compartment and vents to the atmosphere at a slight overpressure. Estimating a heat input of 25 BTU/hr (from both heat shorts and radiation losses) approximately 1 lb. of water per day is required. At 160 psia (mean surface pressure) the boiling temperature is $\sim$ 360°F which is, consequently, the environment experienced by the interior payload compartment. (At higher altitudes, the boiling temperature of course, is somewhat reduced.) The payload area is insulated from the water jacket by an additional evacuated layer and additional reflective insulations. Assuming 150°F as the maximum internal operating pressure an estimated 5 BTU/hr heat input results from the water jacket and an additional 5 BTU/hr is generated internally from probe subsystems.

A total of 10 BTU/hr must be removed internally which is achieved by a separate ice/water reservoir provided for this purpose. Approximately 1 lb. of coolant per day is required.

Designing for one month operation, 60 lbs. (or approximately 1 $ft.^3$) of ice/water is included in the payload contingency. Departures from the estimated heating results merely in varied operation lifetime since the cooling system is strictly passive.

Additional Systems (Low Altitude Devices)

To support the total payload, a 13 ft. diameter balloon is required. The balloon weighs approximately 110 lbs. and the inflator 20 lbs. Allowing another 20 lbs. for the deployment container and 15 lbs. for a deployment chute, the total floater system is 275 lbs.

Since a fairly substantial quantity of inflator is needed, the 11/1 storage growth factor is prohibitive and the balloon must be inflated from a central reservoir on the entry shell. A 4/1 storage growth factor is assumed which includes valves and fittings as well as the storage system. Thus, an additional 80 lbs. is charged to the floater. The disadvantages of this system is that it introduces considerable balloon deployment and valving complexity.

7.3.2 Intermediate Floaters

(a) Passive

The passive "intermediate" floaters are Kapton balloons with 60° corner reflectors deployed inside the balloon cavity. As stated earlier, this configuration is commonly used for weather stations and as ballistic missile decoys (to simulate the warhead radar cross sections). To achieve adequate gain differential over the low altitude floaters, balloon sizes of approximately 20 ft. are required.

(b) Active/Actively Cooled

The actively cooled systems are similar to the low altitude floater with three exceptions. First, Kapton balloon material is substituted for the steel weave. Second, inflator weight is reduced sufficiently which allows inflator bottle storage (at 11/1 storage to inflator ratio), and third, the coolant weight is reduced by approximately half.

7.3.3 High Altitudes Floaters

These floaters operate in the cooler regions and, therefore, only an active system is considered. In this case, a cooling system is not required. Furthermore, standard Mylar balloon material is useable.

7.4 Probe Deployment

Each floater is packaged in a separate cannister in a column stacking arrangement, as shown in Figure 4. A 30° entry cone is selected for compatibility with the packaging configuration. The cone is approximately 11 ft. in diameter and the ballistic parameter $M/C_DA = 1.0$. A pilot chute is deployed at Mach No. between $1.5 \leq M \leq 2.0$ when 3 g's are sensed on-board. (The gee versus Mach No. relation depends on the entry condition, but is reasonably insensitive to atmospheric model within this range.) The chute is maintained through the transonic regime for stabilization. The first balloon cannister is released by the chute upon a 1 g signal, i.e., approximately terminal conditions, and the second chute is subsequently deployed. This sequence is repeated until all cannisters are jettisoned as shown in Figure 5.

Deployment of inflation is approximately 75-90 seconds. For the Kapton and Mylar balloons a maximum dynamic pressure (q) of 1 psf is allowed for deployment. For the steel weave maximum deployment q's are increased to approximately 5-10 psf.

7.5 Weight Summary

Individual probe weights are listed in Table I. Based on a floater complement of 2 low, 2 intermediate and 2 high altitude floaters, total payload weight is given below for both passive and active systems.

		COMPLEMENT I		COMPLEMENT II	
ALTITUDE	NUMBERS	TYPE	WEIGHT	TYPE	WEIGHT
Low	2	Passive	510	Active	710
Inter-mediate	2	Passive	314	Active	330
High	2	Active	256	Active	256
TOTAL	6	Passive Active	1,080	Active	1,296
Entry Systems	1	-	650	-	784
Entry Weight	-	-	1,730	-	2,070

METEOROLOGICAL PROBE WEIGHT SUMMARY

Meteorological Devices

ITEM	LOW ALTITUDE PASSIVE		LOW ALTITUDE ACTIVE	INTERMEDIATE ALTITUDE PASSIVE	INTERMEDIATE ALTITUDE ACTIVE	HIGH ALTITUDE ACTIVE
BALLOON DIAMETER (FT)	6	12	13	20	16	21
Balloon	90	140	110	20	10	13
Reflector	5	15	-	50	-	-
Inflator	7	11	20	6	5	4
Inflator Storage*	77	120	80	66	55	44*
Parachute*	10	15	15	5	10	7*
Structures	6	10	20	5	15	10
Communications	-	-	15	-	15	15
Power	-	-	30	-	30	30
Coolant	-	-	60	-	30	-
Science	-	-	5	-	5	5
Ballast	5	5	-	5	-	-
TOTAL	200	316	355	157	175	128
DEPLOYED	107	171	260	81	110	77

*Discarded prior to full deployment

TABLE I

8.0 HIGH ALTITUDE BUOYANT VENUS DEVICE (BVD)

Introduction

The principal purpose of a buoyant Venus probe is biological exploration in the planet's atmosphere. Though the presumed rigorous conditions at the Venusian surface and near it may preclude the existence of life there, the upper atmosphere cannot be ruled out as a possible abode of primitive "aerosol life." The advantage of the BVD in the search for life lies in its comparatively large payload capacity and in its expected long lifetime in an environment not necessarily hositle to primitive life. The high altitude floater operates at altitudes within the temperate belt (Figure 6) since this region offers the greatest probability of fostering life as we know it. The BVD is maintained aloft by a 82 ft balloon with an inflator re-supply sufficient to ensure a lifetime of at least one to six months.

8.1 Mission Mode

Altitude and site selection for deployment of a high altitude floater is predicated on the extensive atmospheric data obtained from drop sonde and meteorological probes during the first 1977 triple planet flyby encounter. Accurate temperature pressure and density profiles ensure that the altitudes most likely to support biological forms are explored. Furthermore, knowledge of the circulation patterns ensures maximum floater drift range coverage which could substantially increase the probability of detecting life forms. Turbulence data obtained from first encounter probes ensures selection of the safest regions for deployment and initial operations.

During the first several hours after deployment, the BVD communicates directly to the spacecraft to accommodate selected experiments requiring high bit rates. A minimum two hour early arrival time is required to accomplish entry, deployment, and systems checkout, and to ensure that at least an hour will be available for performance of experiments and data transmittal with the flyby module in line-of-sight. This must be accomplished entirely during the approach phase since the spacecraft permanently disappears from view just prior to periapsis.

Subsequently, for long term operations, the probe communicates to earth via an orbiter relay link at a substantially reduced bit rate. Precursor knowledge of the atmospheric circulation patterns enables selection of the optimum orbiter longitude and inclination to maintain the communications relay for the longest possible duration. Experiments data is stored and transmitted on command from the orbiter as the orbiter passes overhead.

8.2 Payload Subsystems

8.2.1 Experiments (by M. Liwshitz)

The exploration of life on-board the BVD proceeds along two main avenues.

1. In the morphological approach the ambient atmosphere or aerosols samples from it are probed for the presence of micro-organisms by means of the electron microscope and phase contrast microscope envisioned for the BVD. A small electron microscope, with a resolution of ∿ 100 Å, and weighing ∿ 50 lbs,* will take about 100 pictures just prior to the flyby vehicle's passage. These will be viewed by vidicon, digitalized and stored on tape.

   The total data content is about 10^8 bits. As the flyby vehicle's approach to the planet permits a high communication range, a reduced sample of the stored data, corresponding to a resolution of ∿ 500 Å is transmitted to the spacecraft. As soon as interesting data are encountered, the transmitter aboard the BVD plays back on command the interesting portion of the tape, corresponding to the higher level of resolution. In this way the total number of bits transmitted can be expected to be on the order of ∿ 2×10^7. The phase contrast microscope operates in a similar fashion, but with a maximum resolution of ∿ 0.25 μ, and also utilizes the above recording system. The weight of the phase contrast microscope is estimated at ∿ 10 lbs. The weight of the recording system with ∿ 10^8 bit capacity is estimated at ∿ 40 lbs. The combined peak power requirement of the entire system is estimated at ∿ 0.5 kw, of which ∿ 4/5 are used only during the few minutes of electron microscope operation or adjustment.

2. The other type of biological experiment included in the BVD payload is best characterized as a growth and metabolism experiment which combines features of several life detection experiments proposed for advanced planetary missions. Aerosol or dust particles, collected by appropriate collection devices are introduced into small chambers, containing different organic nutrients. As these compounds are metabolized by micro-organisms the gases released in the process undergo analysis by a variety of instruments such as IR, UV and visible

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*At present low weight fixed focus models are available commercially, and a reduction in weight by a factor 2 - 4 by the mid 70's appear entirely feasible.

spectrophotometers, a gas chromatograph and mass spectrometer operated in tandem, etc. An exponential rate of growth is considered typical of biological activity of growing cultures and, thus, serves as a distinctive indicator of life. Monitoring of process rates applies also to the observation of physical changes, in the liquid phase of the nutrients. This is accomplished by means of a spectrophotometer in the visible portion of the spectrum, looking for changes in turbidity, and PH meter.

Since growth is a relatively slow process, on a time scale of $\sim$ 1 hour or so, this experiment requires emplacement on a long lived probe such as the BVD; and continues long after departure of the flyby vehicle, such that data will be transmitted to the orbiter, serving as a relay station to earth. The information rate of this experiment is relatively high. The IR spectrophotometer scans the spectrum between 3×10^3 and 10^4 cm^{-1} with a resolution of $\sim$ 10 cm^{-1}; the gas chromatograph mass spectrometer scans the particle spectrum from 1 - 250 AMU. Combined with other apparatus in the biological experiment the total data output per scan is estimated at $\sim 1.5 \times 10^5$ bits/scan are obtained. Inclusion of a moderately sized logic system in the experiment will, however, result in significant data compression. The data will be transmitted to the orbiter at a rate of 4×10^2 bps interlaced with $\sim 5 \times 10^3$ bps from tape storage acquired during the period of the orbiter's trajectory, when it is out of communication range with the BVD. The total weight of the growth experiment and accessories is estimated at $\sim$ 80 lbs; the power requirements at less than 0.5 kw.

In addition to the biological experiment payload the BVD will carry 50 lbs. of experiments for observation of the atmospheric environment. These are of rather conventional types and will not be described in detail. Some components of the bio-experiment, such as the gas chromatograph mass spectrometer will also be utilized for atmospheric study.

The weights summary of the experiments complement is given in the table below:

	BIOLOGY EXPERIMENTS ON BVD	WT. (lbs)
1)	Electron Microscope	50
2)	Recorder	50
3)	Mass Spec - Gas Chr.	30
4)	Culture Growth Experiment w/ Spectrophometer	50
	NON-BIOLOGY EXPERIMENTS	
1)	Pressure Sensors	1
2)	Temperature Sensors	1
3)	Densitometer	1
4)	Speed of Sound	3
5)	Aerosol Detector	4
6)	Rad. Counters (particle)	3
7)	E. M. Rad. Counters	8
8)	Radar Alt.	8
9)	Rate Gyro	2
10)	Tracking Beacon (R.F.)	10
11)	Spherics Detector	4
12)	Magnetometer	5
		230

8.2.2 Power and Communication

The communications subsystem of the BVD consists of an omni-directional antenna and a 20 w S-band transmitter, with a transmission capacity of $\sim 10^6$ bps to the flyby vehicle and 10^4 bps to the orbiter. Its weight is estimated at 60 lbs.

Power is supplied by an RTG system similar in concept to the SNAP-27 for ALSEP experiments. The average prime power required is approximately 350 watts. Batteries are used during short term flyby experiments operation to match high bit rate power requirements.

8.3 Entry and Deployment

Gross system weight at entry is approximately 3,100 lbs. Entry is achieved by a 33° cone of approximately 12 ft diameter with a ballistic parameter of about .6 slugs/ft^2 as shown in Figure 7. A stabilization and extraction chute is deployed to provide transonic stabilization, and a positive extraction force to assist in deployment of the balloon floater upon reaching the terminal regime. Balloon technology and air deployment are the critical aspects in the success of probe performance and are, therefore, discussed in detail below:

The bio-lab and associated payload are to be carried by a 82 ft diameter floater. Based on demonstrated performance of small air deployed balloon systems (10-30 ft) there is little doubt about the feasibility of developing mechanisms for air deployment of balloons of the size considered here. As of now, however, little data exists concerning aerodynamic loads, skin stresses and whiplash effects experienced by balloons deployed in this fashion. Rule of thumb dictates a maximum free stream dynamic pressure ($\bar{q}$) of 1 psf for Mylar film balloons, which requires an extremely large deployment chute for the larger BVD payload.[19,20] Relatively heavy, but extremely rugged nylon weave balloons have been deployed at q's of up to 25 to 30 psf, and nylon Paraglider configurations have been deployed at higher dynamic pressures.[12] This is not achievable with the Mylar system, however, since the heavy laminate Mylar does not have satisfactory folding qualities for packaging, and is also found to possess "self-destructive" characteristics during deployment. Based on the over-riding requirements of achieving reliable and uncomplex deployment, the nylon balloon is selected, although as much as a 500 lb weight penalty results. High strength fibers such as PBI are not yet operational, and at any rate do not appear to have any performance advantage in the temperature regimes considered. Dynamic pressure at initial deployment is limited to 25 psf which should be well within the capability of the material selected and would eliminate the need for any parachute except for the stabilization and extraction chute.

The deployment sequence is initiated at an altitude of about 140,000 ft. A 20 ft. diameter pilot chute ($C_DA = 250$, subsonic) is deployed when a 3 g signal is sensed on-board, ensuring chute deployment at Mach No. $M \leq 1.5$. The inflation time required for the balloon is about seven minutes. Correspondingly, the time required for descent to the 80,000 ft. altitude (neglecting balloon drag), is on the order of nine minutes, thus ensuring full deployment before the high temperatures are reached.

The deployment mode is illustrated in Figure 8. Here the parachute provides transonic stability and slows the shell to a terminal $q \approx 12$ psf. The balloon is deployed by attachment to a high strength balloon cap upon a 1 g signal (indicating the near terminal conditions). Rip ties are employed to prevent dynamic snatch loadings as the balloon is extracted under the constant chute force. The chute performs the additional function of inhibiting flagging action that could tend to tear up the balloon. The entry cone is separated at a dynamic pressure under 5 psf. Upon inflation, the payload nests close to the balloon to minimize dynamic snatch loads during the operational lifetime due to atmospheric instability.

8.4 Balloon Systems

To achieve satisfactory reliability and to allow high $\bar{q}$ deployment the balloon is fabricated of heavy duty nylon fabric which is bonded to Mylar film filler. The properties and performance of this material listed below:

- 2 layers type GT-21 gauge Mylar
- 1 layer 4.0 oz/yd^2, 22 x 22 count nylon in a plain weave
- GT 201 Schjel-Bond, polyester based, thermostat adhesive.

Weight	.004 lbs/ft^2
Service Temperature	-75 to +230°F
Intermittent Temperature	-100 to +350°F
Permeability to H_2	.0014 ft^3/ft^2/day/atm @ 75°F
Tensile Strength, Ultimate	200 lbs/in.

The material has a service temperature limit of 230°F and an intermittent, or sporadic, limit of 350°F. During balloon inflation the system, therefore, must not sink lower than 80,000 ft. (minimum atmosphere model) which is governing deployment consideration.

The fairly extensive temperate bank (between 0 to 100°F) believed to exist between the surface and the cloud tops is predicted at altitudes of 130,000, 170,000 and 200,00 feet, for the minimum, mean, and maximum atmospheres, respectively.[9] The minimum atmosphere is critical for payload design requirements and, consequently, is used for probe sizing and weight estimation. It may be noted that any buoyancy variations due to the increased density of the mean and maximum atmospheres can be accommodated in the present design by partial flooding of the balloon cavity.

The balloon is to be an H_2 inflated super pressure balloon operating with a slight over-pressure of about 1 to 10 millibars. This type of balloon is sealed from the atmosphere and maintains a constant buoyancy regardless of the thermal cycle experienced by the balloon during operations. Super pressure balloons are long duration systems, some small meteorological balloons having been in operation (floating for over six months.[21]

Experience has shown that, for long life systems operating at low temperatures, permeability has not been a sever problem. For the specific material selected here, the permeability is .0014 ft^3/ft^2/day/atm @ 75°F. The permeability doubles at approximately 125°F and is halved at 40°F.

(Operations will be principally between 0 to 100°F so that the nominal is a good value for estimating resupply requirements.) For an 82 ft balloon the inflator loss is considerably less than 1 lb/day. Approximately 100 lbs of H_2 resupply is provided to ensure 1 to 6 months lifetime.

A principal limit to the duration of present systems is balloon icing at high altitudes causing severe loww of altitude and possibly destruction. Icing or hydrocarbon coating could perhaps be eliminated on the BVD by cycling to lower, hotter altitudes, and by dropping ballast.

Cycling to lower altitudes of the temperate region is accomplished by flooding the balloon cavity. At altitudes between 125,000 and 150,000 ft the buoyancy gradient for an 82 ft balloon is approximately 1 lb/1,000 ft. Therefore, cycling by alternately dropping ballast and atmosphere flooding should not be too expensive. Neutral buoyancy is, of course, extremely sensitive to weight variation so a closed loop thermostat/ altimeter control system is required to maintain operation in the desired region. Most probably steady cycling about a selected altitude will result with perturbing amplitudes of at least several thousand feet experienced.

8.5 Inflation System

The initial inflation system is a Hydrogen/Oxygen Demand Pressurization Cycle Catalytic ignition system. Estimated total system weight is 2.55 lb/lb of inflator.[22] The storage system is in the entry cone and discarded with the shell.

The resupply is provided by a hydrogen convective cooled heater system, similar to the cryogenic system on the lunar LM vehicle, sized to use waste heat of the RTG. Estimated system weight is 2.0 lbs/lb of inflator[22] which can be readily accommodated in the present design.

8.6 Weights Summary

The BVD weights summary based on the preceeding system design is given below:

Entry	3100
Entry Systems	1100
Initial Inflator Storage	200
Total Deployed	∿1800

Subsystems Weight Summary

Balloon (82')	760
Initial Inflator	130
Resupply Inflator	100
Resupply Storage	100
Power (RTG and Batteries-- 500 Watts)	300
Structures and Chute	120
Communications	60
Science	230

9.0 NEAR SURFACE FLOATER

Introduction

The Near Surface Floater (NSF) is designed to operate between 5,000 to 10,000 ft. above the Venusian surface and to descend to altitudes as low as several hundred feet if atmospheric conditions permit. The purpose of the probe is the exploration of the planet's lower atmosphere and, conditions permitting, aerial surface reconnaissance, aerosol and surface sample acquisition, and subsequent on-board analysis. Conceptually, the probe is a derivative of the deep submergence spheres used in the scientific exploration of the seas. Rather than contending with extremely high pressures, as do the sea explorers, severe temperature is the principal design constraint for the NSF.

9.1 Density/Temperature Tradeoff

The high density of the Venusian surface atmosphere allows weight penalties imposed by subsystems necessary for operation in this environment to be accommodated in payloads deployed by relatively small, lightweight floaters. To appreciate this deployment capability, Figure 9 illustrates the displaced weight versus balloon diameter for the estimated surface density given by the "minimum" atmosphere model. Atmosphere density here is 23 lbs/100 ft^3 (the "mean" and "maximum" atmosphere densities by comparison are 35 lbs/100 ft^3 and 120 lbs/100 ft^3, respectively). In the minimum density atmosphere, a 30 ft. balloon, for example, displaces 3,100 lbs. (vs. 740 lbs. on earth). By comparison, the same balloon displaces 105 pounds in the temperate region at 140,000 feet, a factor of 30 difference. Compared to floaters operating at higher altitudes, a rather substantial contingency may be allocated for environmental control, and yet meet reasonable weight, packaging, and deployment constraints to ensure successful near surface operations.

9.2 Brief NSF Design Description

Before entering more detailed discussions, the unique aspects of the probe design--all essentially governed by operation in the high temperature environment--are briefly highlighted to give some basic insight into the type of system considered here.

Design of a balloon to deploy and perform reliably in the near surface environment requires an impermeable, high strength fabric capable of withstanding temperatures to 1,000°F for a duration of several months. As discussed in detail in a previous section, a fabric composed of super-alloy steel fiber weave, impregnated with silicon polymer filler, satisfies all of these requirements and appears to be quite capable of operations in the Venusian surface environment.

Another critical design area is thermal protection for payload subsystems. In the present design a double walled evacuated spherical pressure shell is employed to provide a protective shroud for the payload and service systems. (Evacuation is necessary to reduce conduction losses to tolerable levels.) Furthermore, the interior is completely enclosed in an H_2 vapor shield which provides active temperature control. Penetrations (i.e., bosses, leads, sensors, etc.) are conduction cooled by multiple coils, which are chilled by vapor shield bleed off. A liquid hydrogen reservoir supplies the coolant which, upon passage from the coils is vented into the balloon cavity to serve as inflator makeup. (The LH_2 pressurization system is based on the supercritical He system used in the LM with subcritical H_2 substituted as the working fluid.) The specific weight of the storage system is conservatively estimated to be 2 lbs/lb LH_2 so that the cooling system can be provided well within a reasonable weight allotment.

9.3 Mission Mode

The NSF has a 3,400 lb. gross weight at entry and weighs approximately 2,140 lb. deployed. The probe is delivered during the 1978 dual planet flyby to a site and altitude whose selection is predicated on data obtained from aerodrag and meteorological probes operating during the first encounter of the 1977 triple planet flyby. The probe arrives at least two hours prior to periapsis and upon deployment transmits data to the spacecraft at high bit rates. Thereafter, operations are coupled to a relay orbiter for communications to earth. The orbiter is injected into a highly elliptic orbit to minimize injection propulsion weight and to ensure long term tracking capability. Precursory knowledge of the long term drift patterns enables selection of the optimum orbiter longitude and inclination for maintaining communications for a minimum of several weeks. Experiments data are stored and transmitted on command from the orbiter as the orbiter passes overhead.

The NSF is fully deployed at an altitude of approximately 20,000 ft. and gradually descends to an altitude of 5,000 to 10,000 ft. After performing selected experiments in this region the probe begins a slow descent to the surface. A RADVS and accelerometers sense the probes relative ground speed and the severity of atmosphere turbulence. Should conditions that are prohibitive to near surface operations be sensed during descent the probe ascends to a safe altitude and commences long term, high altitude reconnaissance and aerosol sample analysis. If conditions are found to be favorable in the regime of approximately 1,000 to 2,000 ft. the probe is anchored at a selected site and commences high resolution reconnaissance. The probe is next lowered by a winch to several hundred feet. If this mode is achieved, a multispectral, high resolution ground survey is undertaken and a sample acquired via a "clam shell" or "sticky string" device which is lowered to the surface. Temperature hardened experiments (i.e., seismometer, magnetometer, weather station) designed for short term operations are also emplaced at the sample site.

Upon completion of surface operations the anchor system is discarded and the probe drifts at an altitude at which circulation ensures extensive range coverage.

9.4 Experiments

In its initial deployment mode at an altitude between 5,000 to 10,000 ft. the NSF is to accomplish several objectives. First, it is to serve as an "active" meteorological device to measure drift range and range rate, and to acquire data on shock spectra and storm effects. Secondly, it is to provide very precise atmospheric temperature, pressure, density, and composition data. In addition, the extent and nature of near surface atmosphere contaminants (i.e., dust and volcanic ash), and the design constraints imposed by such contaminants (i.e., depositing film on windows) are to be determined. The altitude, extent, opacity, and distribution of surface cloud layers, if they exist, are also to be studied.

Should the surface atmosphere be found calm and placid, as many theories now conjecture (and as may be verified by precursory meteorological probe data), the floater descends and commences surface operations. In this mode the more intriguing experiments include:

1. Surface sample acquisition at several selected sites via a "clam shell" device, and subsequent on-board analysis,

2. Multi-spectral surface photography by low intensity TV (Artificial illumination may be provided by beacons and flares),

3. Sensors deployed directly to selected regions on the surface (i.e., mountains, liquidous regions).

Operating near the surface or in the 5,000 - 10,000 ft. region, additional experiments include:

1. Aerosol filtration,

2. Surface field intensity measurements (i.e., radioactivity),

3. Stereo photography (visible, infrared),

4. Coarse mapping of the spatial distribution of surface, and sub-surface constituants.

Suitable instruments for the various experiments were selected with the assistance of R. N. Kostoff and their principal functions are described below:

A. Aerosol and Surface Sample Analysis:

Pyrolysis Gas Chromatograph - Vaporizes the sample and analyzes the gas components.

X-Ray Spectrometer - Emits an electron beam which interacts with the sample and measures the resulting X-radiation energies.

Gamma-Ray Spectrometer - Measures the photon emission of naturally occurring sample radioisotopes and relates the photon energies to emitting atoms.

TV Microscope - Observes the sample prior to analysis.

B. Environmental:

RADVS - Measures the probes altitude relative to surface as required for guidance, and yields wind current data.

TV Camera - Scans the surface of the planet and observes the sample environment. (The camera views the environment through quartz windows in the pressure shell.)

I.R. Radiometer - Measures the average surface temperature distribution.

Spherics Detector - Detects electrical storms.

Magnetometer - Measures the local magnetic field.

Disdrometer - Measures particle sizes from .3 to 10 μ dia.

Photometer (6) - Measures light intensity distribution.

Thermodynamic Probes - Measures pressure, temperature and density.

Microphones - Measure environmental sonic disturbances.

Flares and Floodlights - Provide lighting for low intensity TV surface photography.

C. Emplaced Environment Experiments

Seismometer - Measures ground response to internal disturbances

Weather Station - Monitors sample environment

The estimated weight and power requirements are summarized below:

Experiment	Weight (lbs)	Power (watts)
Pyrolysis Gas Chromatograph	14	70
X-Ray Spectrometer	20	20

Gamma-Ray Spectrometer	13	2	
TV Microscope	10	100	
RADVUS	35	40	
TV Camera	10	100	
I.R. Radiometer	5	3	
Spherics Detector	4	2	
Magnetometer	4	5	
Disdrometer	4	3	
Photometers (6)	4	2	
Thermodynamics	6	4	
Microphones	3	4	
Flares and Floodlights	10	100	(average)
Seismometer	7	1	
Weather Station	40	10	
	189	366	

9.5 Anchor System

To establish residence in the vicinity of a selected site, an anchor (i.e., grappling hook or weight), suspended from a cable of approximately 2,000 ft length, is lowered to the surface. (By comparison 17,000 ft tethers have been used for experimental balloon platforms in the earth's atmosphere and 60,000 tethers are presently under consideration.) The cable is 1/8 in high strength steel weighing .05 lbs/ft or a total of 100 lbs. Assuming a minimum vertical (i.e., buoyant) force of 100 lbs and a balloon C_D of .25, the 2,000 ft cable allows the balloon to float at altitudes of approximately 800 ft in a 10 MPH wind and 200 ft in a 30 MPH wind. The cable, governed by minimum gage considerations, can as designed to withstand a maximum wind gust of 50 MPH. It may be noted that as the balloon descends in steep cross winds, the equilibrium elevation approaches ground level asymptotically tending to reduce the change of surface contact. (In the case of downdrafts the cable comes in contact with the surface, reducing the buoyant weight, and causes the balloon to rise again.) In the absence of downdrafts the probe should be able to descent on the cable to $\sim$ 100 ft elevation if a secure connection is achieved.

Operating in the anchored mode a clam shell or sticky string device is lowered when low relative ground speed (i.e., less than 2 MPH) is sensed. This cable is approximately 1,000 ft in length and weighs 20 lbs (.02 lbs/ft). Allowing an additional 10 lbs for a mechanical winch, and 20 lbs for the clam shell recovery system weighs 50 lbs. Upon acquisition of a sample, the recovery system is drawn into an air lock for viewing by TV under environmental conditions. The sample is then chilled to room temperature for analysis.

9.6 Probe Description

The probe configuration is shown in Figure 10. The payload is protected by a double layer evacuated pressure shell which is suspended from a 30 ft. diameter woven steel balloon. The outer shell is 6 ft. in diameter and fabricated of semi-monocoque beryllium skin. Cooling is provided by a liquid H_2 reservoir[22] which is bled into a vapor shield completely surrounding the payload. From the vapor shield the coolant is vented through coils surrounding bosses, separators, wire leads and other penetrations through the shell, and ultimately to the balloon cavity for inflation resupply. Inside the shell convective cooling is provided to keep a uniform and essentially constant temperature. The LH_2 pressurization system is based on the super-critical He system as used in the LM with sub-critical H_2 substituted as the working fluid. The system is conservatively estimated to have a specific weight of 2 lb/lb LH_2 including coolant, conservative cryogenic material tankage, insulation, electrical fittings, fill and vents, and associated plumbing. Estimates indicate that a minimum of several weeks duration, desired for adequate range coverage, is achievable with 80 lbs. of LH_2 refrigerant. After cooling payload subsystems the H_2 vapor is vented into the balloon cavity for makeup gas. If necessary, a portion of the H_2 vapor is bled directly from the reservoir to cool instrument subsystems by convection cooling (at the expense of probe duration).

9.6.1 Power and Communication

The comminications subsystem consists of an omni-directional antenna and a 20 w S-band transmitter, with a transmission capacity of $\sim 10^6$ bps to the flyby vehicle and 10^4 bps to the orbiter. Its weight is estimated at 60 lbs.

Approximately 350 watts are required for experiments and 250 watts for prime power or a total of .6 kw. Power is obtained from an RTG which is mounted outside the pressure shell with input leads cooled before entering the instrument compartment. RTG systems operating at 1,200°F with 2 1/2% efficiency are presently under development. The RTG sink temperature could be as low as 700°F if the probe is deployed at the poles or near the lightside terminator, since temperatures in these regions are presumably not as severe as in other sunlit areas.

9.6.2 Balloon System

The balloon is an H_2 inflated super-pressure balloon fabricated of super-alloy steel fiber weave impreganted with silicon polymer filler which as cited earlier, is operational to temperatures between 1,000 to 1,200°F. Below 1,000°F this material has a very low permeability to hydrogen so long life operation can be assured. For a standard 5 to 8 mil material the weight is approximately .21 lbs/ft^2 and the material has a strength of 200 lbs/ft. The super-alloy weave is readily folded and has the handling qualities of cloth fabric.

The payload is supported by a membrane transition cone of similar material providing a snug hold between payload and balloon to constrain relative motion. The initial inflation system is a Hydrogen/Oxygen Demand Pressurization Cycle-Catalytic ignition system. Estimated system weight is 2.55 lb/lb of inflator. The initial inflator storage system is discarded shortly after inflation when the entry shell is jettisoned.

9.6.3 Altitude Stabilization

The buoyancy gradient for the 30' balloon is approximately 40 lbs/1,000 ft. in the near surface regime so that satisfactory altitude stabilization should be achievable, i.e., ±40 lbs in gross weight would change the floatation altitude by ±1000 feet. Initial floatation altitude is to be at 10,000 ft. Controlled flooding of the balloon cavity with atmosphere would assure slow and controlled descent to perhaps within 1,000 ft. (without anchoring) if the near surface conditions are found to be quiescent. Ranging devices and altimeters are to constantly monitor the surface to ensure adequate time to avoid obstructions. In the sample acquisition mode, vernier altitude stabilization is provided by inflation/deflation of a small balloon in the main balloon cone cavity (used to prevent excessive inflator/atmosphere mixing). The balloon is approximately 7 ft. in diameter and provides a controlled buoyant force of 40 lbs. (i.e., 1,000 ft. altitude) variation. A servo control system coupled to a RADVS devices in this manner controls the altitude to ±300 ft without tethering.

9.7 Deployment

The probe is stowed in a 14 ft. 33° entry cone as shown in Figure 11. The ballistic parameter $M/C_DA = 1.0$ and the entry angle is on the order of -13°. A pilot chute is deployed at a Mach No. $1.5<M<2.0$ when 3 g's are sensed on-board. (A gee signal is a good indication of deployment Mach numbers as previously mentioned) The pilot chute of approximately 20' diameter (C_DA = 250 ft^2 - subsonic) performs several roles. It provides stabilization through the transonic regime, exerts a positive extraction force for balloon deployment and retards balloon flagging during the inflation period.

Initial balloon extraction occurs at a dynamic pressure just under 12 psf. Brake ties are employed during balloon pull-out to reduce the dynamic snatch loads. A total of about 7 minutes are required for inflation during the descent. At a dynamic pressure on the order of 5 psf the entry shell (including the initial inflation package), is released and falls away under a small ejection force. When fully inflated, the balloon restricts any relative motion between the payload and itself, minimizing any dynamic snatch loadings during operation.

9.8 Weight Summary

The NSF weight breakdown summary is given below:

Entry Weight	3400
Entry Systems	1100
Initial Inflator Storage (Discarded)	290
Initial Inflator	230
Balloon Weight (30')	600
Inflator Resupply & Coolant	170
Pressure Shell	120
Power (.6 kw)	400
Communications	100
Structure & Insulation	150
Anchor & Clam Shell	190
Science	200
Total Deployed Weight	2140

HJ Fondon For DE Cassidy

D. E. Cassidy

C. L. Davis

for M. H. Skeer

DEC
1013-CLD-nmm
MHS

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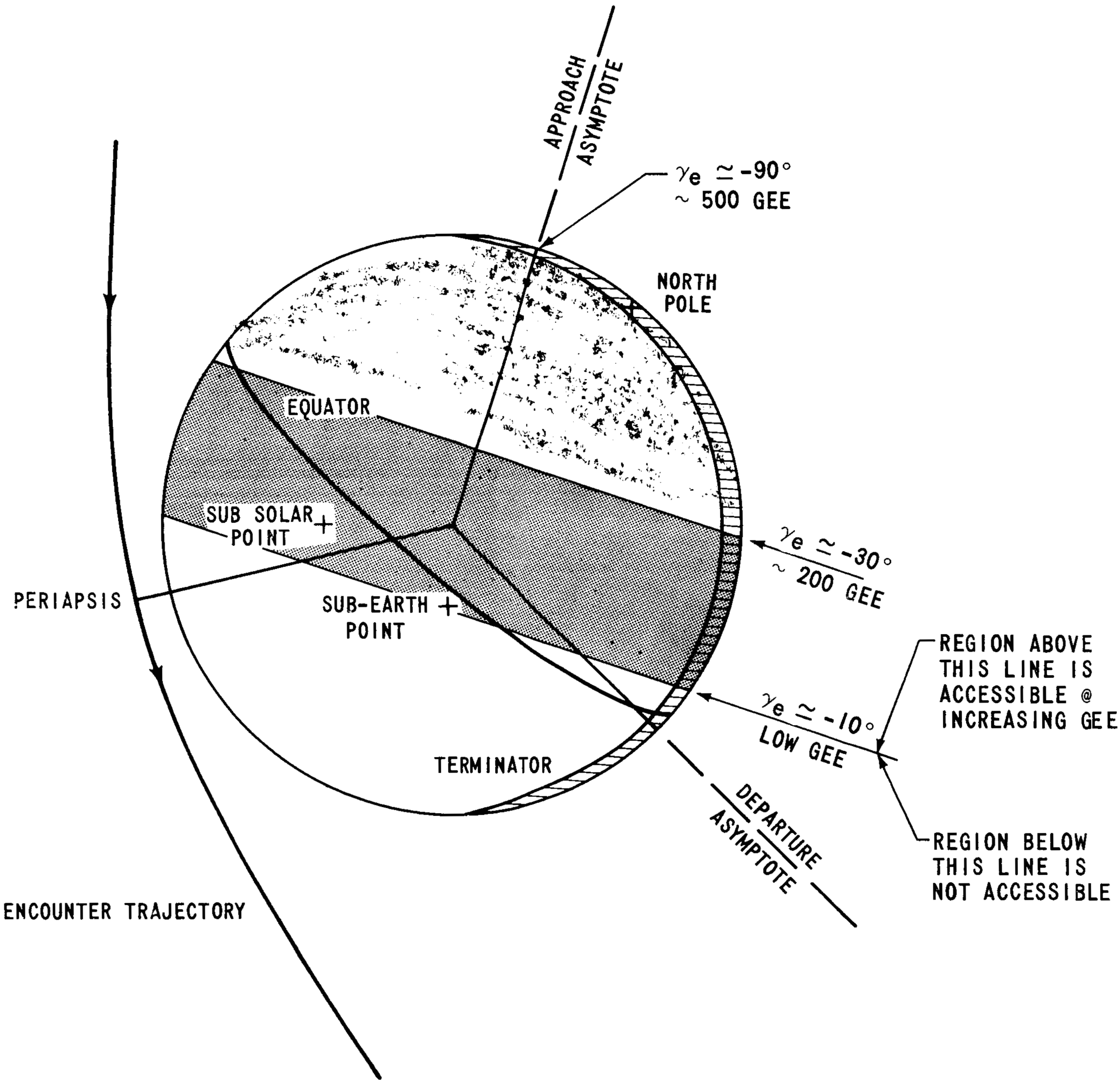
VENUS PASSAGE DATE	6/21/77
VENUS PASSAGE DISTANCE	680 KM
ARRIVAL - DEPARTURE V_∞	6.7 KM/SEC
VELOCITY AT PERIAPSIS	11.8 KM/SEC

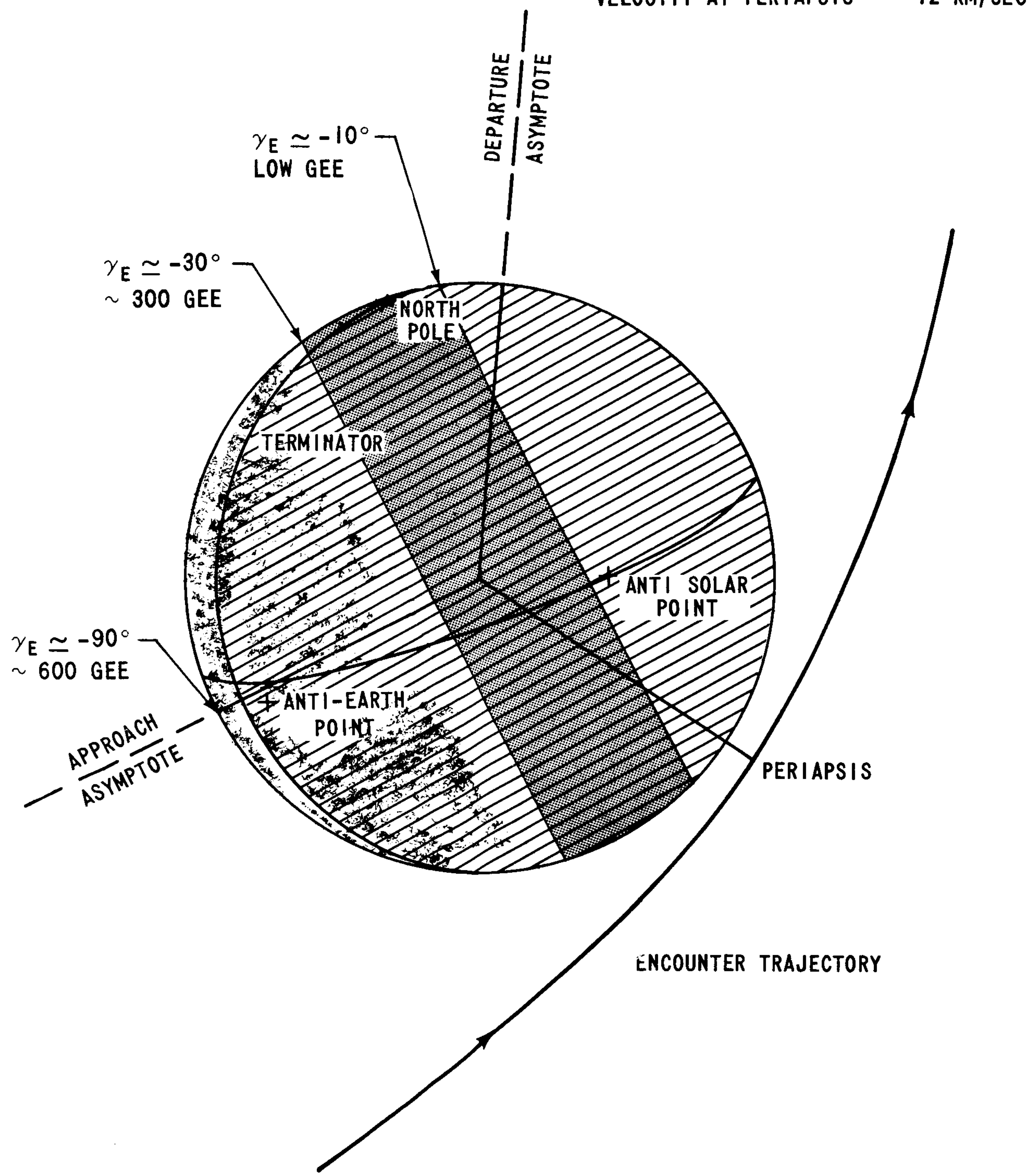


INCLINATION OF FLYBY PLANE TO VENUS EQUATORIAL PLANE 80.4°

FIRST VENUS ENCOUNTER

FIGURE 1A - 1977 TRIPLE PLANET MISSION

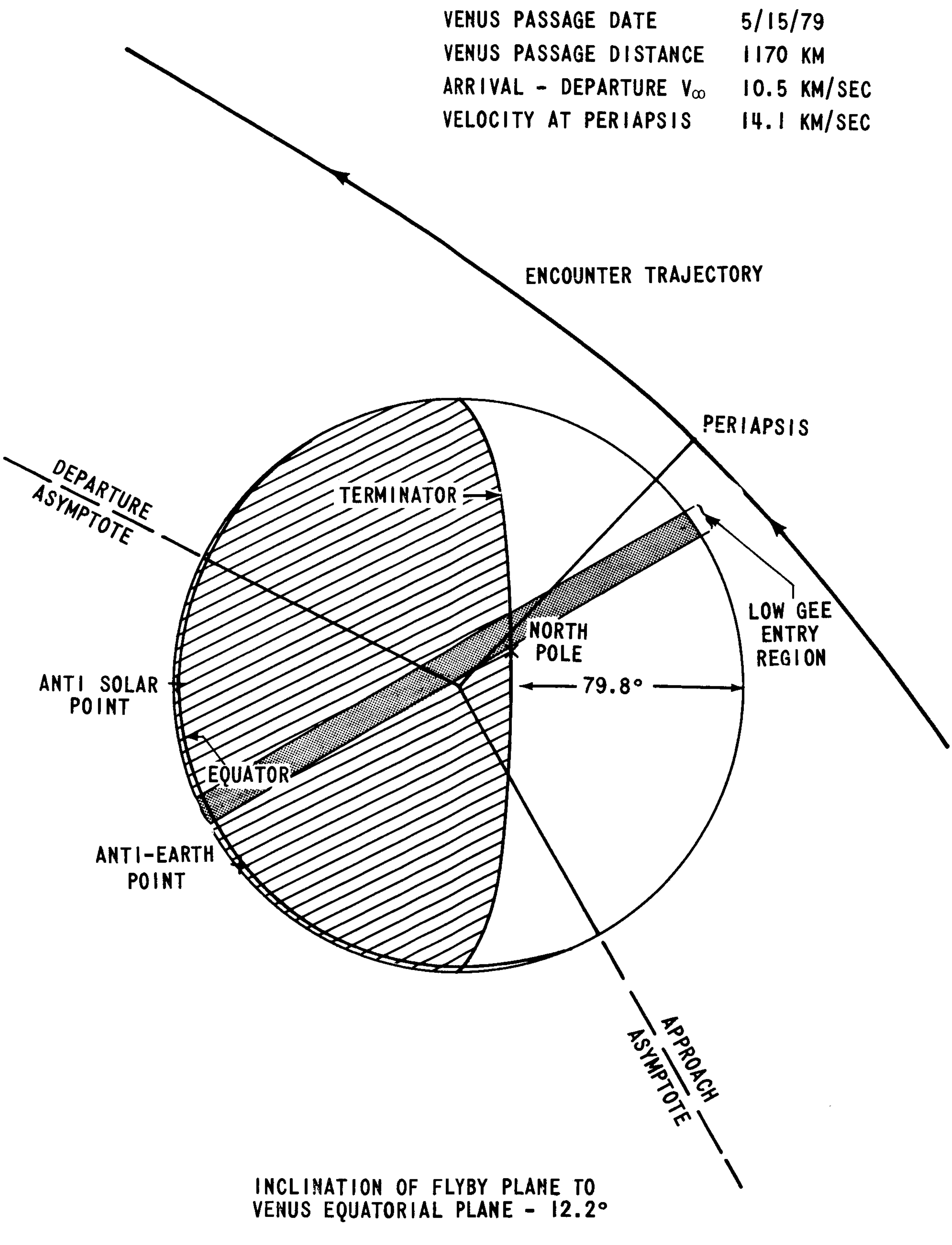
VENUS PASSAGE DATE	8/20/78
VENUS PASSAGE DISTANCE	700 KM
ARRIVAL - DEPARTURE V_∞	7.1 KM/SEC
VELOCITY AT PERIAPSIS	12 KM/SEC



INCLINATION OF FLYBY PLANE TO
VENUS EQUATORIAL PLANE - 80.5°

SECOND VENUS ENCOUNTER

FIGURE 1B - 1977 TRIPLE PLANET MISSION



VENUS ENCOUNTER

FIGURE 1C - 1978 DUAL PLANET MISSION

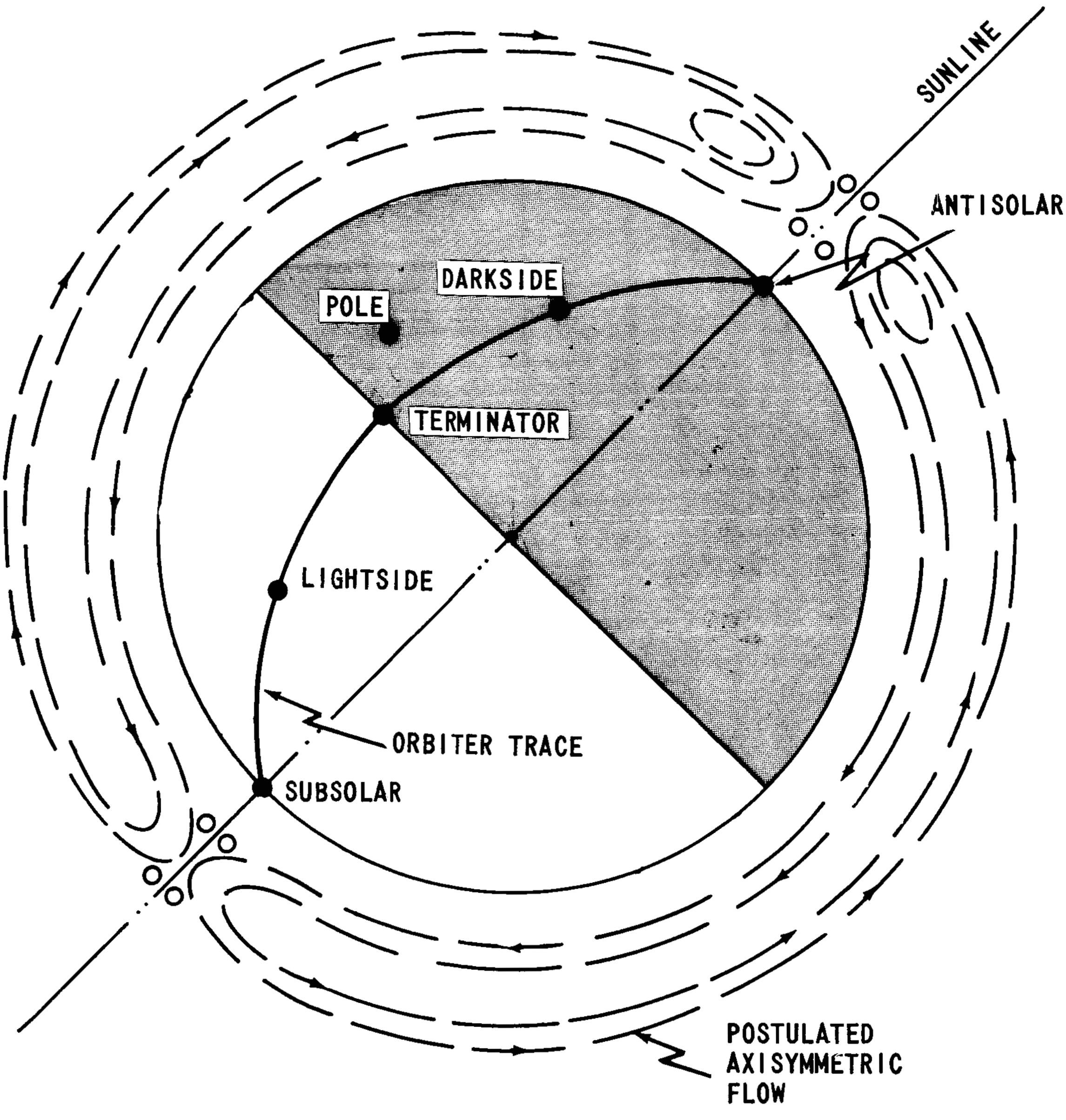


FIGURE 2 - DESIRED SPATIAL DISTRIBUTION OF METEOROLOGICAL DEVICES

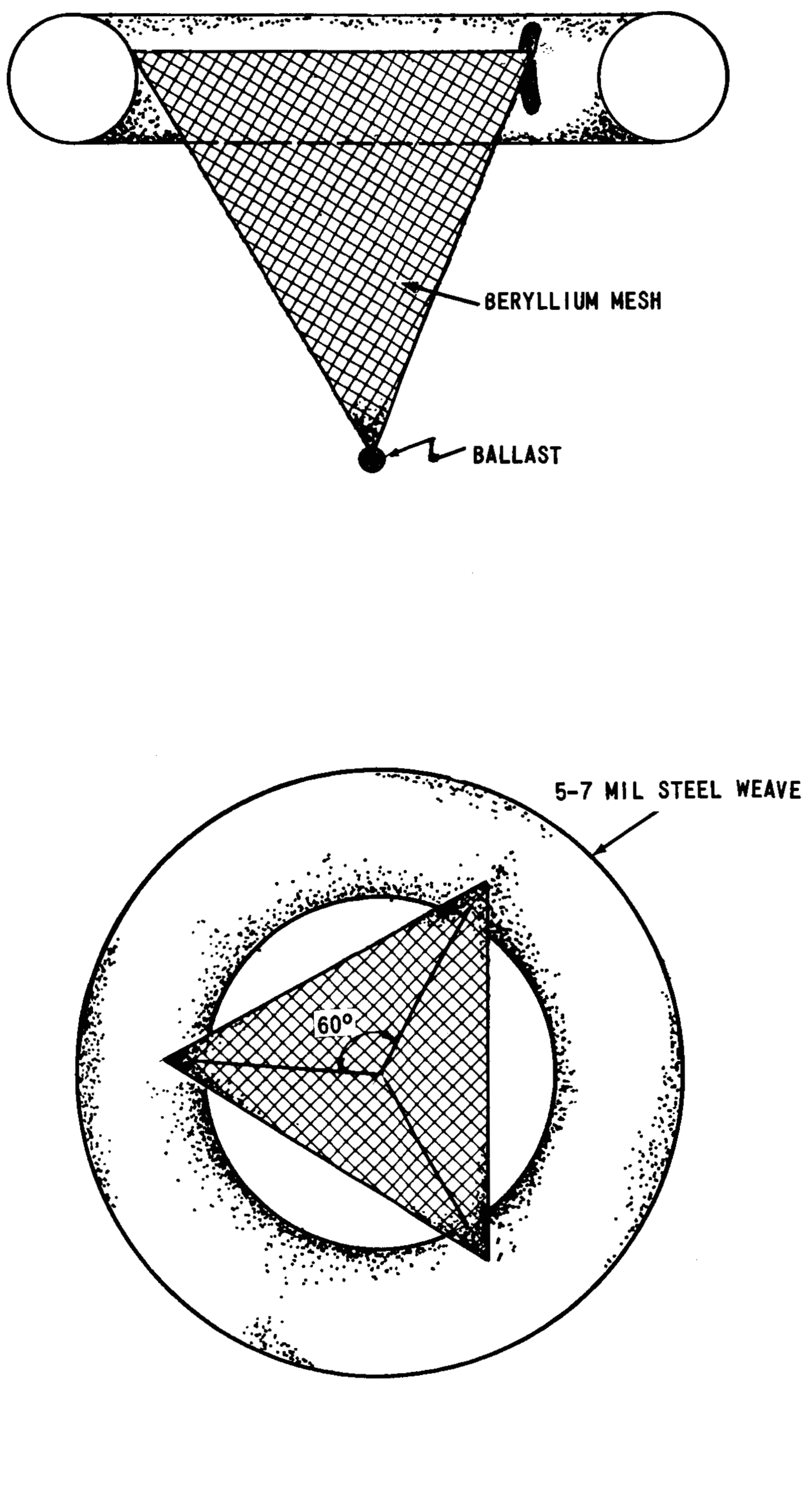


FIGURE 3 - PASSIVE FLOATER/60^0 TRIANGULAR TETRAHEDRAL REFLECTOR

METEOROLOGICAL DEVICE DESCRIPTION

33° ENTRY CONE DIAMETER = 11'
$M/C_DA = 1.0$
ENTRY WEIGHT = 1730/2070 FOR PASSIVE/ACTIVE COMPLEMENT
DEPLOYED WEIGHT (TOTAL) = 1080/1296 FOR PASSIVE/ACTIVE COMPLEMENT

FLOATER WEIGHT SUMMARY

	PASSIVE	ACTIVE
LOW ALTITUDE (2)	510	710
MEDIUM ALTITUDE (2)	314	330
HIGH ALTITUDE (2)	256	256
ENTRY SYSTEMS	650	784
TOTAL	1,730	2,070

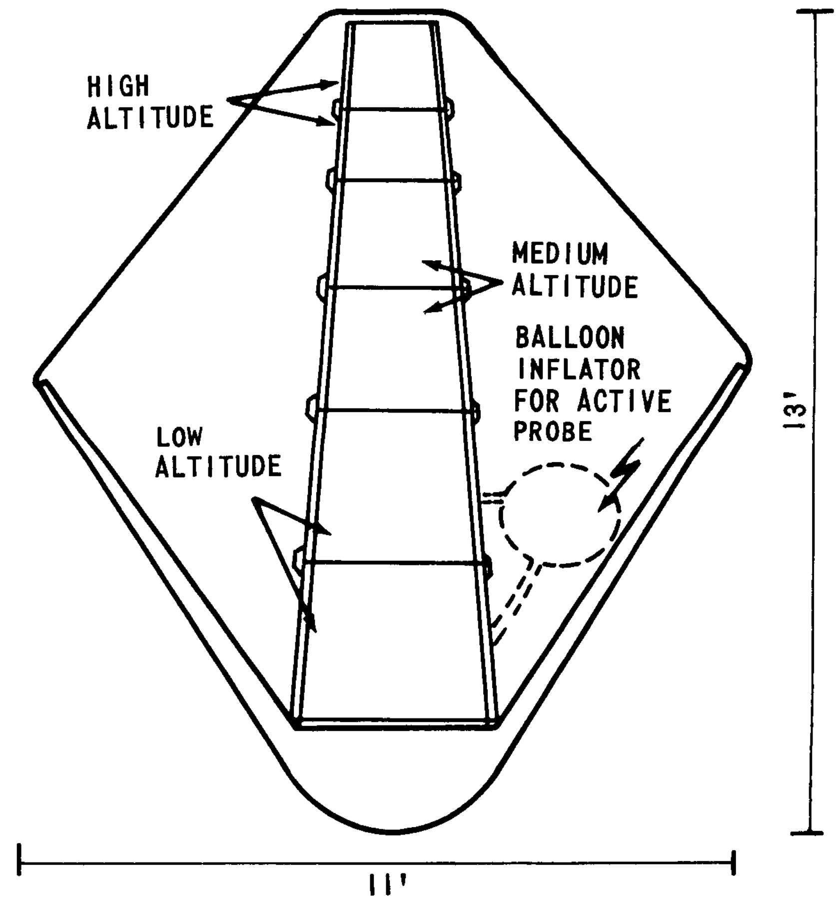


FIGURE 4 - METEOROLOGICAL DEVICES

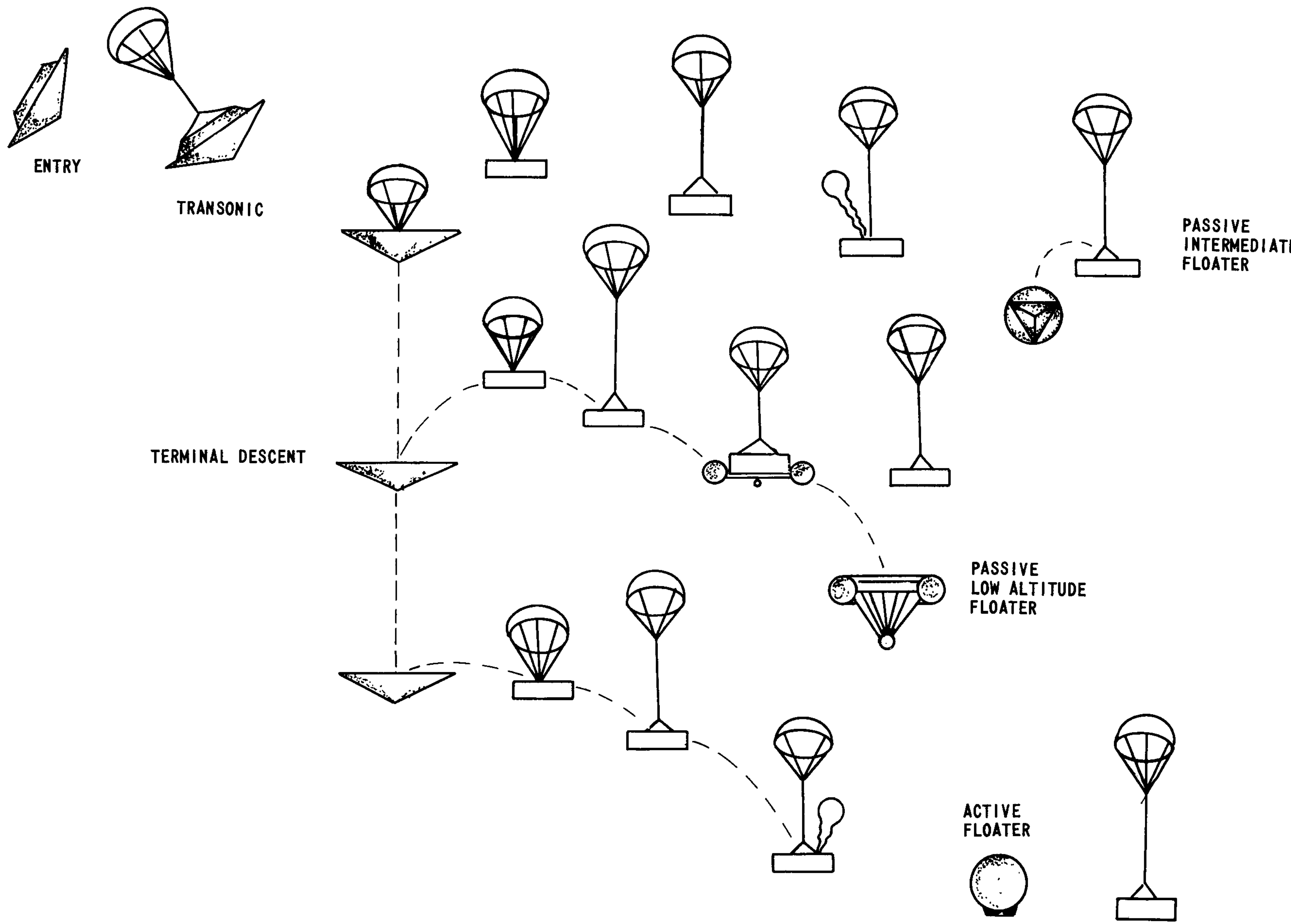


FIGURE 5 - TYPICAL DEPLOYMENT SEQUENCE

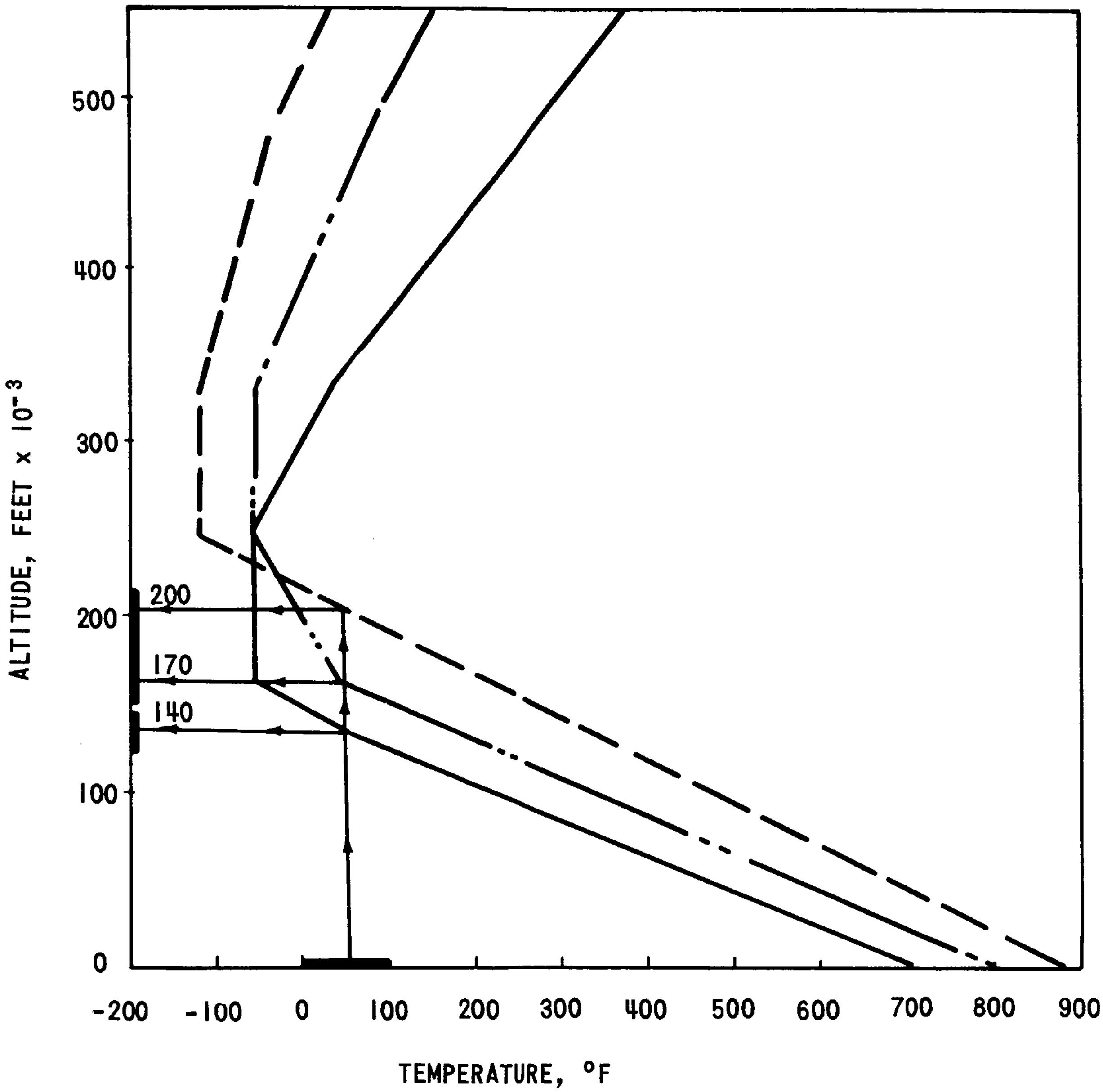


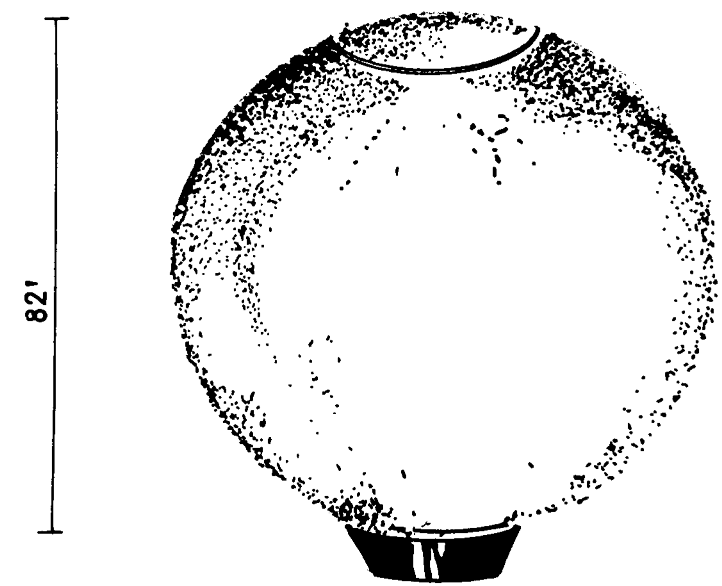
FIGURE 6 - PRESUMED TEMPERATE REGIONS

BVD DESCRIPTION

BALLOON DIAMETER = 82'
33^{o} ENTRY CONE DIAMETER = 12'
M/C_DA = .65
ENTRY WEIGHT = 3100 LBS
DEPLOYED WEIGHT = 1700 LBS

SUBSYSTEMS WEIGHT SUMMARY

ENTRY SYSTEMS	1100	DISCARDED
INFLATOR STORAGE	200	DISCARDED
BALLOON	760	
INITIAL INFLATOR	130	
RESUPPLY INFLATOR	100	
RESUPPLY STORAGE	100	
POWER (RTG & BATTERIES)	300	
STRUCTURES & CHUTE	120	
COMMUNICATIONS	60	
SCIENCE	230	



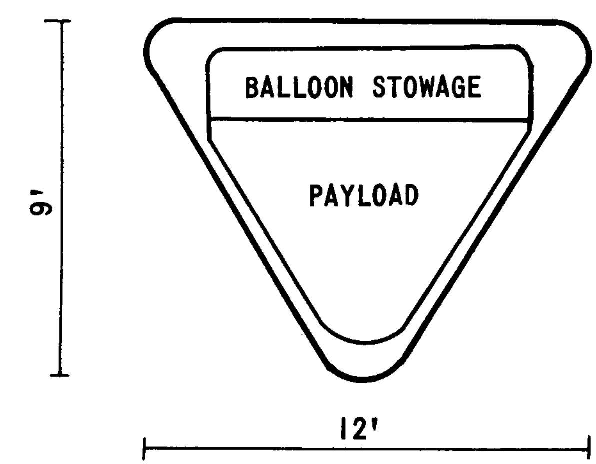


FIGURE 7 - BVD SUMMARY

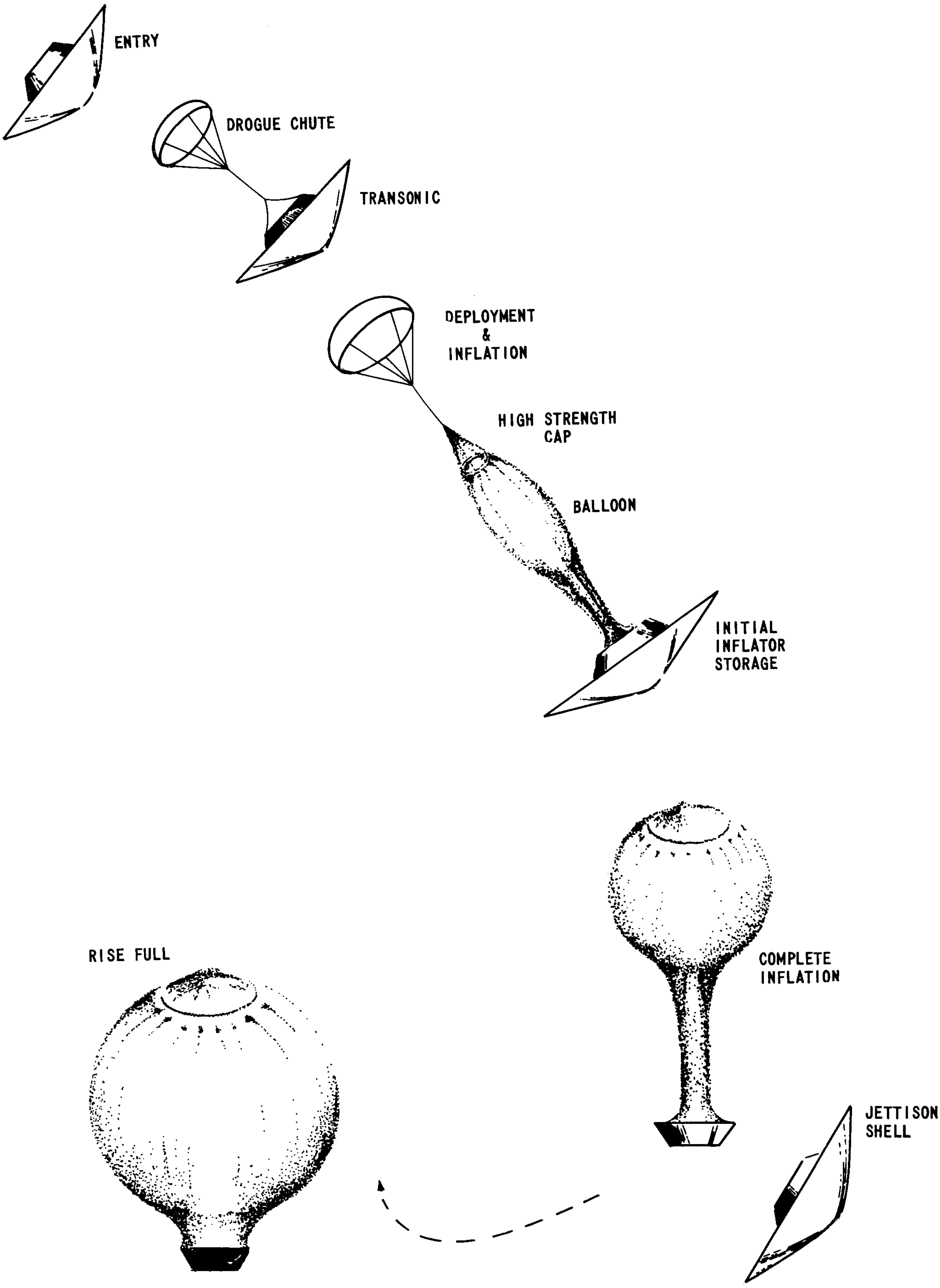


FIGURE 8 - BALLOON DEPLOYMENT

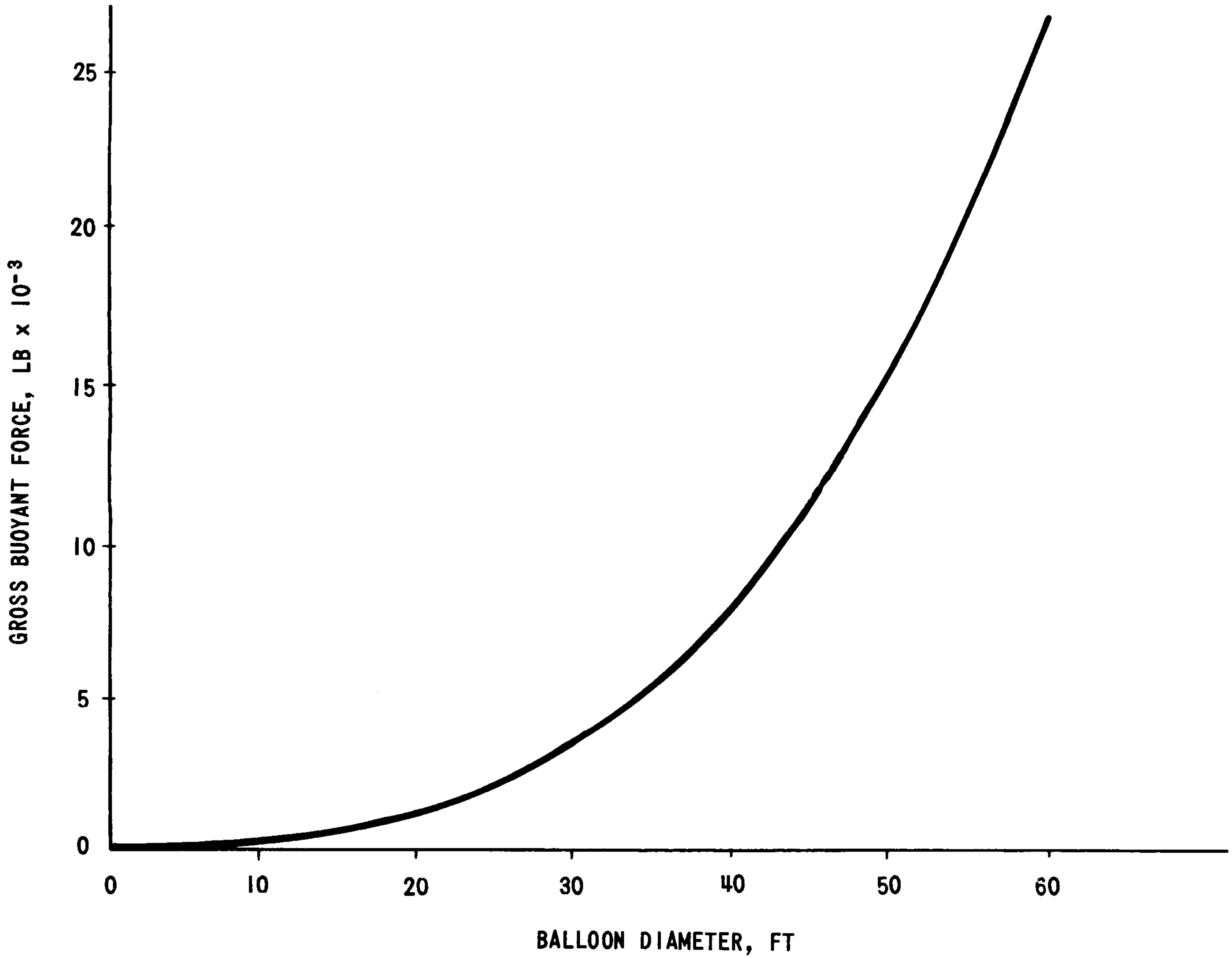


FIGURE 9 - DISPLACED WEIGHT OF BALLOON IN VENUSIAN SURFACE ATMOSPHERE - MINIMUM DENSITY MODEL

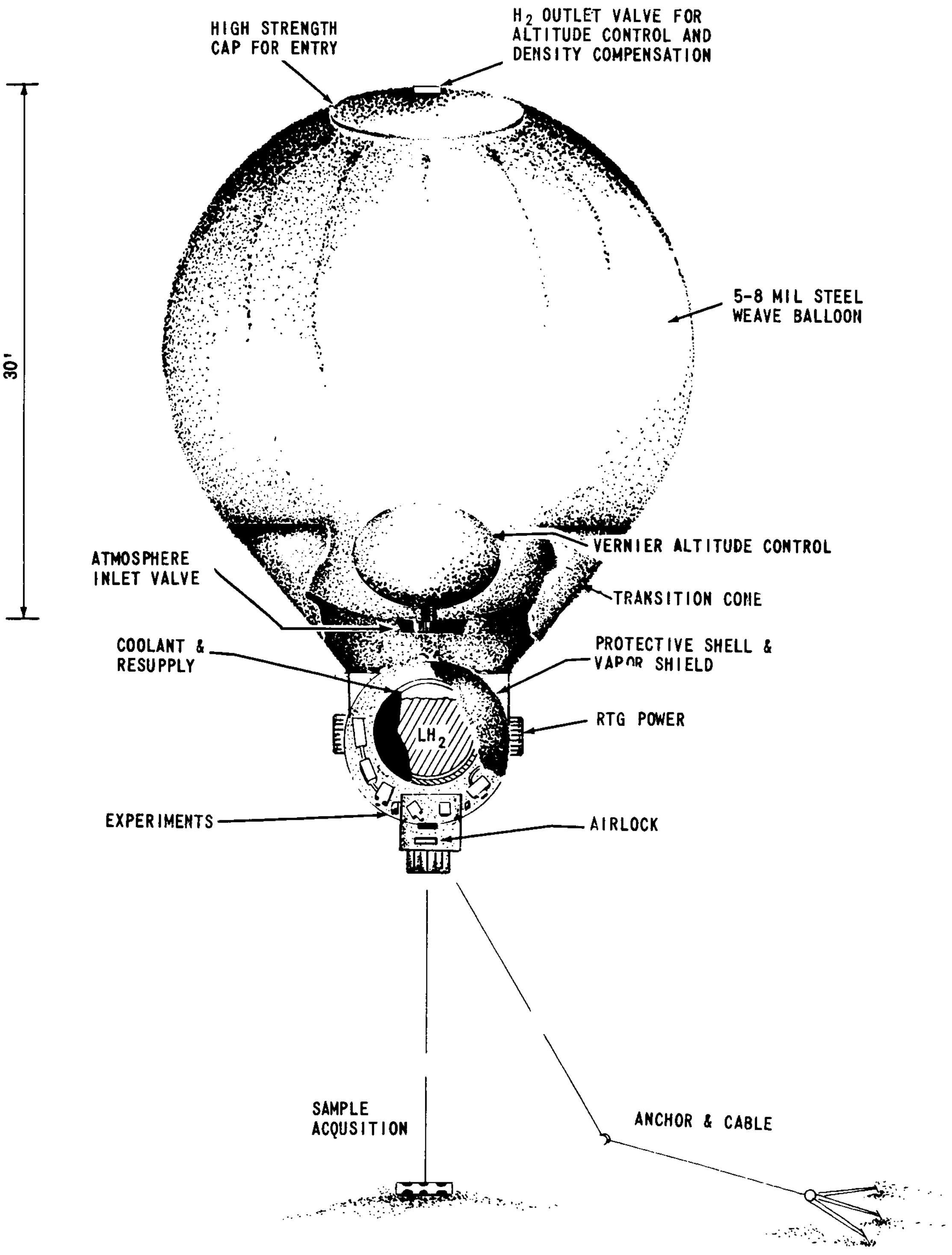


FIGURE 10 - NEAR SURFACE FLOATER IN SAMPLE ACQUISITION MODE

NEAR SURFACE FLOATER

33° ENTRY CONE DIAMETER = 14'
M/C_DA = 1.0
ENTRY WEIGHT = 3400
DEPLOYED WEIGHT = 2140

SUBSYSTEM WEIGHTS SUMMARY

BALLOON (~30')	600
INITIAL INFLATOR	290
INFLATOR STORAGE (DISCARDED)	230
INFLATOR RESUPPLY & COOLANT	170
PRESSURE SHELL	120
POWER (.6 KW)	400
COMMUNICATIONS	100
STRUCTURE & INSULATION	150
ANCHOR & SAMPLE RECOVERY	190
SCIENCE	200
ENTRY SYSTEMS	1100

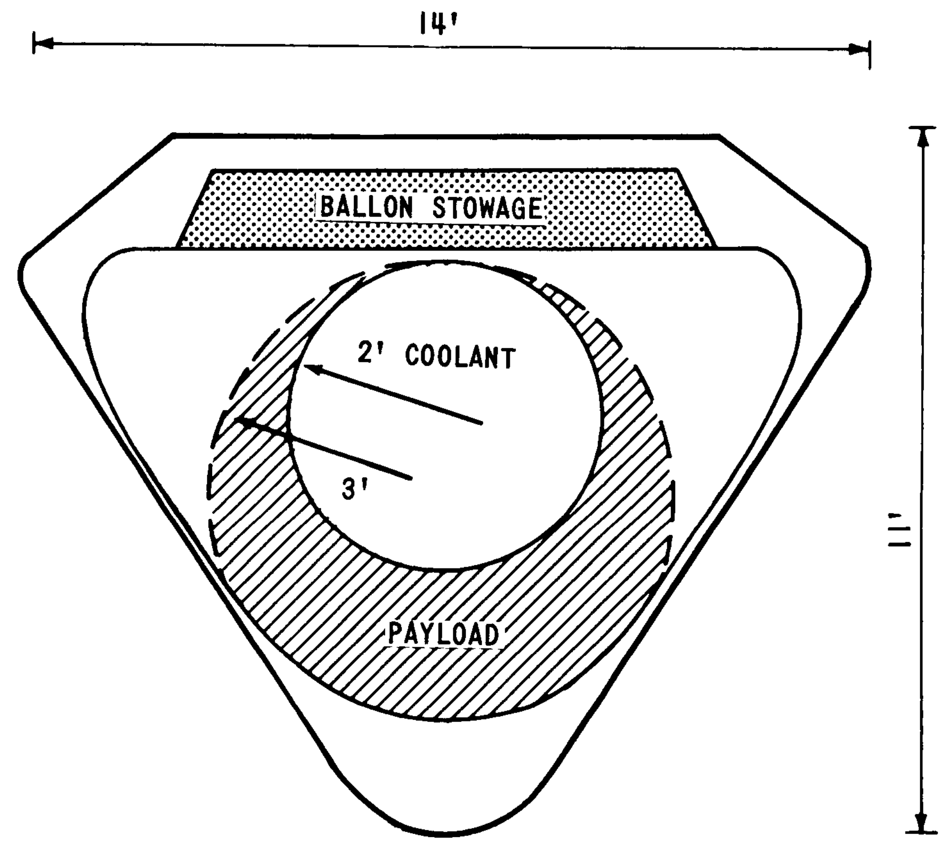


FIGURE 11 - NEAR SURFACE FLOATER

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